DOCUMENT RESUME

ED 195 414 SE 033 405

AUTHOR Macek, Victor C.
TITLE Reactor Statics Module, RS-9: Multigroup Diffusion Program Using an Exponential Acceleration Technique.
INSTITUTION Virginia Polytechnic Inst. and State Univ., Blacksburg. Coll. of Engineering.
SPONS AGENCY National Science Foundation, Washington, D.C.
PUB DATE [73]
GRANT NSF-GZ-2888: NSF-SED73-06276
NOTE 57p.: Contains marginal legibility in computer printouts and tables.

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS *College Science: Computer Assisted Instruction: *Computer Programs: Engineering: *Engineering Education: Engineering Technology: Graduate Study: Higher Education: *Learning Modules: Mathematical Models: *Nuclear Physics: Physics: Programing Languages: Science Education: Science Instruction

ABSTRACT

The nine Reactor Statics Modules are designed to introduce students to the use of numerical methods and digital computers for calculation of neutron flux distributions in space and energy which are needed to calculate criticality, power distribution, and fuel burnup for both slow neutron and fast neutron fission reactors. The last module, RS-9, includes a separate program, WANDIC (one-dimensional diffusion code with three energy-group representation), for the calculations of neutron spectra and group constants for use in fast breeder reactor calculations. It can be used with the criticality programs in RS-2 and RS-8. The reactor is divided into several concentric annular regions and it is assumed that those regions can be represented fairly well by their average properties. The previous modules show how these properties are found. The set of nine modules is intended to supplement textbooks and other lecture material generally available to students in their course work. It is assumed that students are familiar with elementary nuclear structure, neutron-nuclei interactions, and introductory material on fission chain reactors. (Author/SK)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

U S DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Patricia Babb

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

ED195414

SE 033 405

REACTOR STATICS MODULE, RS-9

MULTIGROUP DIFFUSION PROGRAM

USING AN EXPONENTIAL ACCELERATION TECHNIQUE

by

Victor C. Macek

The University gratefully acknowledges the support of the Division of Higher Education of the National Science Foundation for support of this work performed under Grant GZ-2888 and the support of Duke Power Company, North Carolina Power and Light Company, and Virginia Electric and Power Company.

Project Director: Milton C. Edlund

DEC 1 2 1980

Reactor Statics Module, RS-9

Multigroup Diffusion Program Using an Exponential Acceleration Technique

9.1 Introduction

A reactor physicist or a nuclear engineer designing a power reactor needs to know the number of neutrons present within the system. This information is necessary for the calculation of the power distribution in a reactor from which further vital information on other related physical quantities needed to assure a successful operation of the reactor can be derived.

Previous modules discussed a broad area of problems which are encountered in reactor physics design. The basic input for calculations consists of engineering specifications and nuclear data. The former provide quantities like power density, fuel composition and a geometric description of the reactor. This information varies from one design to another. On the other hand, the nuclear data contains detailed cross-section information.

This input starts a rather long string of calculations before one can obtain results in a form which is suitable for engineering application.

The detailed treatment of space-energy physical phenomena in the entire reactor represents a very difficult task. Therefore, the problem is usually divided into several different stages and the flow of calculations passes from the detailed analysis of the neutron balance in an elementary fuel pin cell to the reactor as a whole consisting of assemblies which are represented by their average properties. In this procedure, the spatial and energy effects are reduced in detail; the former through the "homogenization", the latter through the group condensation. Of course, care must be taken in these simplifications. For example, neutron balance must be conserved.

The code WANDIC (one-dimensional diffusion code with a three energy-group representation) which is described in this module can be used to perform the global reactor calculations. The reactor is divided into several concentric annular regions and it is assumed that we can represent those regions fairly well by their average properties. The previous modules show how these properties are found.

Features of WANDIC

9.2 General Description

The program solves the three group diffusion equations

$$D_g \nabla^2 \phi^g - \Sigma_T \phi^g + S^g = 0 \quad \text{for } g = 1,2,3 \tag{9.2.1}$$

where the source term consisting of fission neutrons appears in the highest energy group only. The source terms in the lower groups are due to scattered neutrons from the adjacent upper group. The source S^g is given as

$$S^g = \frac{\delta_{1g}}{K} \sum_{g=1}^{3} (\nu\Sigma_f)^g \phi^g + \Sigma_s^{g-1,g} \phi^{g-1} \tag{9.2.2}$$

where δ_{1g} is Kronecker's delta; $\delta_{1g} = 1$ for $g = 1$, zero otherwise. The group diffusion equations are solved for cylindrical geometry with θ and β symmetries by using a finite difference technique which is described in module RS-2. Fluxes in each group and each mesh-point are calculated by solving a system of linear equations.

$$\begin{aligned} b_1^g \phi_1^g - a_1 \phi_2^g &= S_1^g \\ -c_n^g \phi_{n-1}^g + b_n^g \phi_n^g - a_n^g \phi_n^g &= S_n^g \\ -c_M^g \phi_{M-1} + b_M^g \phi_M^g &= S_{M-1}^g \end{aligned} \tag{9.2.3}$$

where indices 1, M denote mesh-points at the center and outer boundary of the reactor respectively. S_n is the source at the point n.

In matrix form the system (9.2.3) can be written as

$$A^g \phi^g = S^g \tag{9.2.4}$$

where ϕ^g is a vector representing fluxes ϕ_n^g at all mesh-points. The source term is a vector whose components are

$$S_n^g = h_n(\Sigma_{sn}^{g-1,g}\phi_n^{g-1} + \frac{\delta_{1g}}{K} \sum_{j=1}^{3} (\nu\Sigma_f)_n^j \phi_n^j)$$

where h_n is volume of the mesh-interval. In matrix notation S_n^g can be written as

$$S^g = E^g\phi + \frac{\delta_{1g}}{K} F\phi, \tag{9.2.5}$$

where

δ_{1g} is the Kronecker delta and

$$\phi = \begin{bmatrix} \phi^1 \\ \phi^2 \\ \phi^3 \end{bmatrix} \qquad E^g = (E^{1g}\ E^{2g}\ 0)$$
$$F = (F^1\ F^2\ F^3) .$$

The vector ϕ^j is formed from the elements ϕ_n^j, the diagonal matrix E^{jg} is formed from the elements $\Sigma_{sn}^{g-1,g}$, and the diagonal matrix F^j is formed from the elements $(\nu\Sigma_{fn})^j$.

Finally, the assembly of group euqations may also be regarded as a matrix problem, which may be written as

$$\underline{\underline{A}}\ \underline{\phi} = \underline{S}, \tag{9.2.6}$$

where

$$\underline{\underline{A}} = \begin{bmatrix} A^1 & 0 & 0 \\ 0 & A^2 & 0 \\ 0 & 0 & A^3 \end{bmatrix} \qquad \underline{S} = \underline{E}\,\underline{\phi} + \frac{\delta_{1g}}{k}\,\underline{F}\,\underline{\phi}$$

$$\underline{F} = \begin{bmatrix} F^1 \\ F^2 \\ F^3 \end{bmatrix}^T \qquad \underline{E} = \begin{bmatrix} E^1 \\ E^2 \\ E^3 \end{bmatrix}^T .$$

9.3 The Inner Iteration

The inner iteration allows calculation of spatial dependence of fluxes with respect to the boundary conditions. For simple one-dimensional geometries the inner iteration can be avoided and fluxes at each mesh-point calculated by a direct procedure such as Thomas algorithm which is described in Module RS-2, Chapter 2. This algorithm is used in this code.

9.4 The Outer Iteration

The overall matrix problem to be solved is expressed in Eq. (9.2.6) as

$$\underline{\underline{A}}\,\underline{\phi} = \underline{S} \qquad (9.4.1)$$

in which

$$\underline{S} = \underline{E}\,\underline{\phi} + \frac{1}{k}\,\underline{F}\,\underline{\phi} \; . \qquad (9.4.2)$$

The normal procedure is to begin the solution of the group equations in the highest energy group by using a flux guess for the calculation of the fission source. In the highest group there are no slowing-down scattering terms. Proceeding to the next group, the slowing-down part of the source can be calculated from the new fluxes in group 1; since fission source in this model appears only in the highest group, the fission part of the source in group 2 is zero. The calculation can proceed in this fashion to thermal energy. At the end of the outer iteration we have a completely new flux vector, so that the fission source $\underline{F}\,\underline{\phi}$ may be recalculated and the whole process may be repeated.

The equation which must be solved is

$$(A - E)\phi = \frac{1}{k} F \phi. \tag{9.4.3}$$

The iteration process proceeds by defining a vector

$$\psi = \frac{1}{k} F\phi = \frac{1}{k} S \tag{9.4.4}$$

where

$$S = F\phi. \tag{9.4.5}$$

(Note that S denotes the fission source only.)

The iteration is defined by the relation

$$(A - E)\phi^{(p)} = \psi^{(p-1)}. \tag{9.4.6}$$

From Eq. (9.4.5) we can write

$$S^{(p)} = F\phi^{(p)}. \tag{9.4.7}$$

By combining Eqs. (9.4.5) and (1.4.7), the p-th iterate of the source reactor is given by

$$\frac{1}{k^{(p)}} S^{(p)} = \psi^{(p-1)}. \qquad (9.4.7)$$

To estimate the eigenvalue one utilizes the fact that when a convergence is being approached, the fission source for one iteration should equal the fission source for the next. In this code the estimate of the eigenvalue is determined in the following fashion. The iteration starts with $k^{(0)}$ equal to 1 and $S^{(0)}$ such that

$$\int_{(\text{vol of core})} S^{(0)} dv = 1 \qquad (9.4.8)$$

Then from (1.4.7) and (1.4.4),

$$k^{(1)} = \int_{(\text{vol of core})} S^{(1)} dv, \qquad (9.4.9)$$

and similarly

$$k^{(p)} = \int S^{(p)} dv. \qquad (9.4.9)$$

The iteration continues until convergence of the eigenvalue $k^{(p)}$ is obtained, i.e.,

$$\left| \frac{k^{(p)} - k^{(p-1)}}{k^{(p)}} \right| < \varepsilon . \qquad (9.4.10)$$

The single power iteration described above tends to converge rather slowly and acceleration techniques are used to improve the convergence rate. If we denote the unaccelerated fission source for iteration p by $S^{*(p)}$, then we calculate an accelerated fission source from

$$S^{(p)} = S^{(p-1)} + \omega(S^{*(p)} - S^{(p-1)}). \qquad (9.4.11)$$

This form of acceleration is referred to as a first order acceleration. The Chebyshev polynomial method is described Reactor Statics Module, RS-8. The optimum value of ω requires a knowledge of the maximum eigenvalue of the matrix $(A - E)F^{-1}$. Generally this eigenvalue is not known. One of the methods to solve this problem is described in the following section.

9.5 The Exponential Over-Relaxation Technique

The program uses a special technique for the calculation of the source introduced for the subsequent iteration step.

Fission sources are computed from the calculated fluxes at each mesh point as follows

$$S_n^* = \sum_j (\nu\Sigma_f)_n^j \phi_n^j \qquad \begin{matrix} j = 1,2,3 \\ n = 1,2,\ldots \end{matrix} \quad . \tag{9.5.1}$$

For the first iteration the initial source-guess will be, e.g.,

$$S^{(0)} = \frac{1}{\pi R^2} \, , \tag{9.5.2}$$

where R is the radius of the core. The source for the p-th iteration will be given by formula

$$S_n^{(p)} = S_n^{(p-1)} + \omega(S_n^* - S_n^{(p-1)} \, , \tag{9.5.3}$$

where ω is the relaxation factor whose optimal value lies between 1 and 2.

The equation (9.5.3) can be rewritten as

$$\begin{aligned} S_n^{(p)} &= S_n^{(p-1)} [1 + \omega(\frac{S_n^*}{S_n^{(p-1)}} - 1)] \\ S_n^P &= S_n^{(p-1)} \exp[\omega(\frac{S_n^*}{S_n^{(p-1)}} - 1] \end{aligned} \tag{9.5.4}$$

for $(\omega \frac{S_n^*}{S_n^{(p-1)}} - 1) \ll 1$.

The optimal value of the relaxation factor ω is automatically computed during the calculation.

Letting,

$$Q' = \frac{S_n^*}{S_n^{(p-1)}} - 1, \tag{9.5.5}$$

we can have two cases:

1) $Q' > 0$.

The exponential function can be expressed as

$$\exp[\omega(\frac{S_n^*}{S_n^{(p-1)}} - 1] \simeq 1 + \omega(\frac{S_n}{S_n^{(p-1)}} - 1)$$

$$\simeq 2 - (1 - \omega(\frac{S_n^*}{S_n^{(p-1)}} - 1)) \tag{9.5.6}$$

$$\simeq 2 - e^{-Q} \quad ,$$

where

$$Q = \omega^* \left| \frac{S_n^*}{S_n^{(p-1)}} - 1 \right| . \tag{9.5.7}$$

2) $Q' < 0$.

In this case we have

$$\exp[\omega(\frac{S_n^*}{S_n^{(p-1)}} - 1)] = e^{-Q} . \tag{9.5.8}$$

The calculation of the exponential function in the core is speeded up by the following approximations:

For $Q > 0.1$ $\quad e^{-Q} \rightarrow \exp[-Q]$

$0.001 \leq Q \leq 0.1$ $\quad e^{-Q} \rightarrow \frac{1 - Q/2}{1 + Q/2}$

$Q < 0.001$ $\quad e^{-Q} \rightarrow 1 - Q$.

In order to find the optimum value of ω it is necessary to scan the maximum relative error at each iteration given by the expression

$$\varepsilon^{(p)}(S) = \max_i \left(\frac{S_i^{(p)} - S_i^{(p-1)}}{S_i^{(p-1)}} \right) , \qquad (9.5.9)$$

where i runs through all mesh-points. The computation is normally started with ω equal to 1.9. At the end of 20 iterations the convergence ratio is tested. If the convergence is fast enough, let us say, if

$$\frac{\varepsilon^{(10)}(S)}{\varepsilon^{(20)}(S)} > 1.5 , \qquad (9.5.10)$$

the iteration with unchanged ω is continued for another 20 iterations. If the convergence is slow with respect to the above criterion, i.e., the inequality is reversed and if the relative point-wise error oscillates which can be described by the inequality

$$\left| \frac{\varepsilon^{(20)}}{\varepsilon^{(19)}} \left[1 + \left| \varepsilon^{(19)}(S) \right| \right] \right| > 1.0, \qquad (9.5.11)$$

ω is reduced by 0.1 and with this new value of ω the iteration process is continued in the same manner as described above.

9.6 Accuracy Criteria

In this code two criteria for the outer iteration are adopted. The convergence of the multiplication factor k will be reached when the following holds.

$$\left| \frac{k^{(p)} - k^{(p-1)}}{k^{(p)}} \right| < \frac{\varepsilon_1}{5.0} , \qquad (9.6.1)$$

where $k^{(p-1)}$ is the eigenvalue obtained in the previous iteration. Once criticality is obtained, the program proceeds to obtain the pointwise convergence of neutron group fluxes which will be reached when the following condition is fulfilled.

$$\left| \frac{\phi_n^{(p)} - \phi_n^{(p-1)}}{\phi_n^{(p-1)}} \right|_{max} < \varepsilon_2 . \qquad (9.6.2)$$

With the poison search another convergence criterion must be included which is discussed further.

9.7 Control Search

The program does a control search on a poison or any fictitious material which adjusts the reactor to the critical condition. Let the multiplier of the poison concentration be denoted by X. In general, the parameter X can be applied to any other type of control. By changing X the program finds k, then changes X, finds k again, and so on. In the early stages of the process the k calculations stop when both criteria (9.6.1) and (9.6.2) are satisfied. Then the criterion to guarantee criticality is applied, i.e.,

$$|k(\text{converged}) - k_c| < \varepsilon_1, \qquad (9.7.1)$$

if k_c is chosen to be unity, the reactor is critical. Clearly k_c also can be chosen to take into account the presence of other reactivity controls.

The initial guess for the multiplication factor proceeds according to the following formulas:

a) If the first guess for the multiplication factor X is zero, the second guess is

$$X_2 = \Delta X * \{\text{of sign of } (1.0 - k_1)\} . \qquad (9.7.2)$$

b) If the first guess is non-zero the second guess is given by

$$X_2 = 1.0 + \Delta X * \{[\text{sign of } (1.0 - k_1)]\} * X, \qquad (9.7.2)$$

where k is the converged eigenvalue and ΔX is an increment in the

parameter X. This formula tries to ensure that X moves in the right direction: it assumes that if X is negative, an increase of X decreases the reactivity, and the converse of this if X is positive (this would be applied, e.g., for the search of fissile isotopic composition). The programs finishes when three conditions (9.6.1), (9.6.2), and (9.7.1) are satisfied.

With the quantities X_1 and X_2 the search is begun and X is varied in order to make k equal to unity. It is easy enough then to make a simple, search procedure such as ordinary "regula falsi," but these processes appear to be very inefficient in this context. The difficulty is that given X, we can find k but the more accurately we require it, the greater the number of iterations is required. One way to go is to improve "regula falsi" process so that the search is accelerated. In ordinary "regula falsi" at each stop, it is one of the limits (a, b) which is used and the last approximation of the root. Instead of that we can use the last two approximations which are closer to the root which is searched for than the limits of the interval (a, b). The formula which is used has the form given by Equation (9.7.5) and is illustrated in Figure 1.

$$a_{n+1} = a_n - f(a_n) * \frac{a_n - a_{n-1}}{f(a_n) - f(a_{n-1})} . \qquad (9.7.4)$$

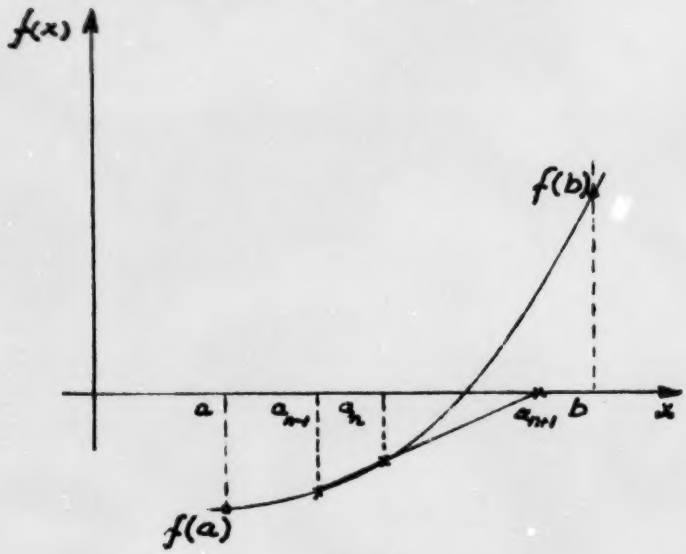


Fig. 1.

The a_1 is found from the formula

$$a_1 = b - f(b)\,\frac{b - a}{f(b) - f(a)}\,. \qquad (9.7.5)$$

Depending on the sign of f(a), f(b), and $f(a_1)$, a_2 is computed from the formula (9.7.6) if $f(a) < 0$, $f(b) > 0$ and $f(a_1) < 0$; if $f(a_1) > 0$ from the formula (9.7.7),

$$a_2 = a_1 - f(a_1)\,\frac{b - a_1}{f(b) - f(a_1)} \qquad (9.7.6)$$

and

$$a_2 = a_1 - f(a_1)\,\frac{a_1 - a}{f(a_1) - f(a)}\,. \qquad (9.7.7)$$

If perchance the point a_3 will appear outside the interval (a, b) then in the following step it will be necessary to consider the closer limit instead of the point a_3. It can be shown that convergence of this method is faster than the ordinary "regular falsi".

9.8 Power Normalization of Neutron Fluxes

The source-normalized power at the point $\vec{r}$ is given by the expression

$$p(\vec{r}) = \sum_1 \kappa_j \Sigma_f^j(\vec{r})\phi^j(\vec{r}) \quad j = 1,2,3 \tag{9.8.1}$$

where $_j$ stands for energy produced per fission reaction, $\phi^j(r)$ is the source-normalized flux. In order to get fluxes normalized to the total power output of the reactor we have to multiply the source normalized fluxes by the normalization factor γ given by the formula

$$\gamma = \frac{P|H}{\int_0^R p(\vec{r})\underline{dr}}, \tag{9.8.2}$$

where $\underline{dr} = 2\pi\, r dr$ and H is the height of the reactor. The power-normalized flux ϕ' is then given by

$$\phi_j'(\vec{r}) = \gamma\phi_j(r). \tag{9.8.3}$$

9.9 Organization of the Program

The code WANDIC has the following limitations

a) Number of energy groups is three

b) The reactor can be divided into four regions from which the outer one is non-multiplicative. If use of fewer regions is desired, the the entry data for some of these regions will be identical.

c) Memory array space is provided for up to 300 mesh-points.

d) Number of intervals dividing each region must be even.

The code consists of a number of subprograms which perform different parts of calculation and are controlled by the main program.

9.10 The Role of Different Subprograms

PLOT: The subprogram participating in preparation of the output and plotting the related results on the printer.

SIMP: The subprogram performing the integration of functions over the core volume by SIMQSON'S rule.

ZERO: The subprogram which employs the accelerated "regula falsi" technique.

9.11 Flow-Chart

Besides its role as the manager of subprograms, the main program is in charge of entry of data for calculation of fluxes and preparation of results for the output. In Figure 2 the flow-chart of the sequence of calculation is presented.

FLOW-CHART A

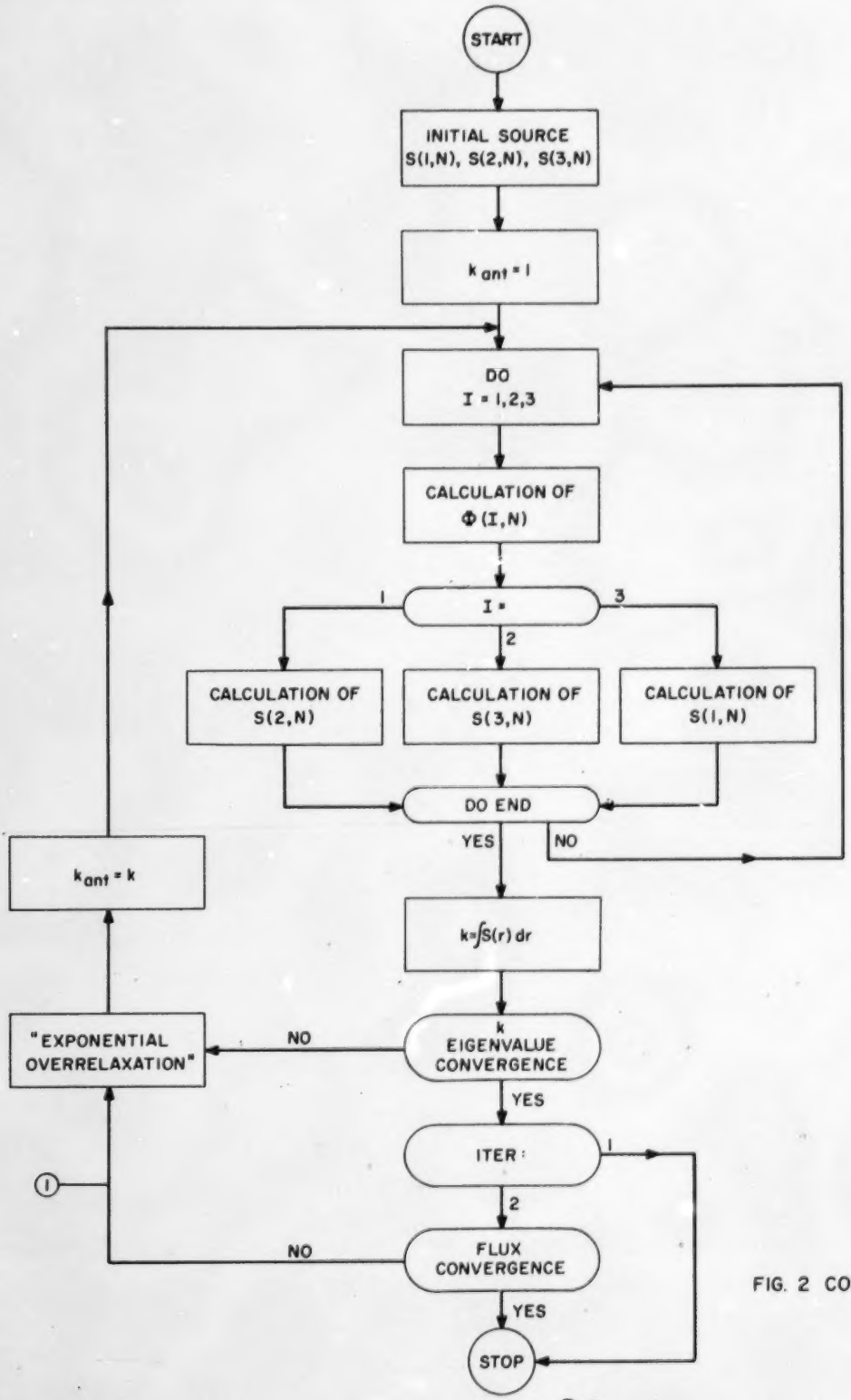


FIG. 2 CON'T.

GENERAL FLOW-CHART OF THE PROGRAM

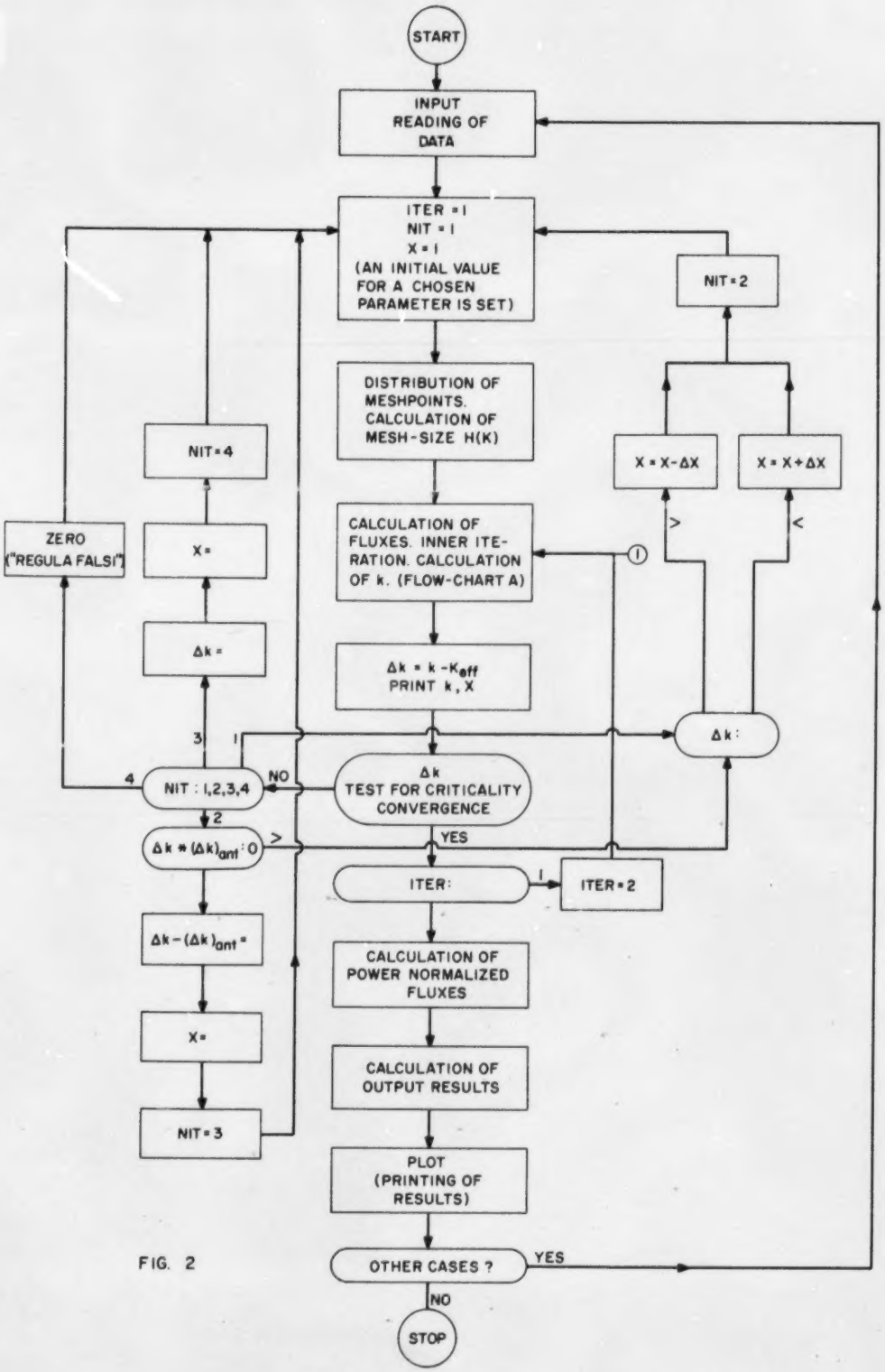


FIG. 2

9.12 Output

The output of the program are:

a) source normalized group fluxes versus radius

b) relative magnitudes of fluxes at each mesh-point with respect to the flux at the symmetry axis of the core

c) ratio of group fluxes

d) eigenvalue of the unpoisoned reactor

e) poison concentration needed for criticality

f) power normalized group fluxes

g) power generated in each fueled region with respective power densities

h) for user who wants to watch the iteration process, printing of eigenvalue K computed at each iteration is provided.

9.13 Names of Principal Variables Used by the Program

H(K): mesh-size of the region K

FLUX(I,N): neutron flux of the group I at the mesh-point N

SDS(N): slowing-down source at the mesh-point N

FS(N): fission source at the mesh-point N

S(N): source at the mesh-point N

EPS(P): maximun relative error for the source on the p-th iteration

FME: $K_c = 1$

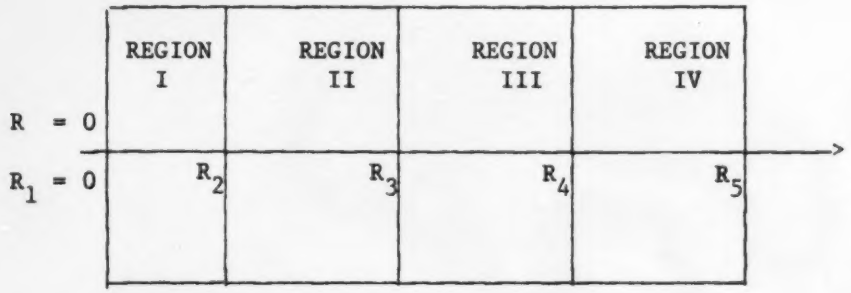
XP: multiplication factor for the control poison cross-section

FMANT: eigenvalue of the preceding iteration

FPR(K): power density of the region K.

9.14 Use of the Program for a Simple Problem. Presentation of Entry of Data

The data introduced here are for illustration purposes only. Consider a cylindrical reactor consisting of three different fissionable regions and a reflector (see figure below). The outer radius of the first region is R_2 = 87.7 cm, the second R_3 = 124.00 cm, R_4 = 152.00 cm, R_5 = 159 cm.



The data for the problem would start:

1 card: symbols used for reading are

OVREL CONV PREC BH2 SCP POW NINT(1) NINT(2) NINT(3)

NINT(4) ICP ICC

where

OVREL: the relaxation factor (Sec. 1.5). This factor for a new problem is put equal to 1.9. Once an "optimum" factor is found, this may be introduced into a set of similar problems (e.g., with the same mesh-point distribution).

CONV: the pointwise flux convergence accuracy number (ε_2). (See Eq. (9.6.2)

PREC: the accuracy (ε_1) for the eigenvalue convergence. (See Eq. (9.6.1).

BH2: axial buckling.

SCP: microscopic cross-section of a poison material for the third group energy level in barns.

POW: thermal output of the reactor in watts.

NINT(K): number of intervals per region K.

ICP: control search parameter. If its value is

1...control poison is considered in region 1

2...region 2

3...region 3

4...all fueled regions

5...regions 1 and 2

6...regions 2 and 3

ICC: is the case control parameter (equal to zero, if only one case is to be treated; positive, if otherwise)

The three group diffusion equations in one of the multiplicative powers assumes, in general, the following form

$$D_1\Delta^2\Phi_1 - (\Sigma_{a_1} + \Sigma_{S_1 1\to 2})\Phi_1 + \sum_{i=1}^{3} \frac{(\nu\Sigma_f)_i\Phi_i}{k} = 0$$

$$D_2\Delta^2\Phi_2 - (\Sigma_{a_2} + \Sigma_{S_1 2\to 3})\Phi_2 + \Sigma_{S_1 1\to 2}\Phi_1 = 0$$

$$D_3\Delta^2\Phi_3 - \Sigma_{a_3}\Phi_3 + \Sigma^1_{S_1 2\to 3}\Phi_2 = 0$$

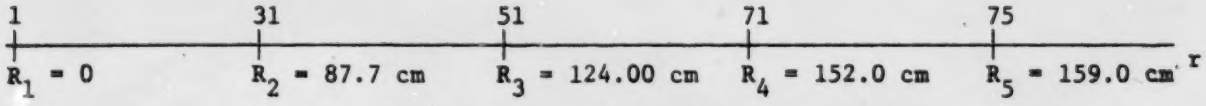
For example, with calculated macroscopic cross-sections

$$1.7\,\Delta^2\Phi_1 - (0.004 + 0.06)\Phi_1 + \frac{1}{k}(0.43\,\Phi_1 + 0.015\,\Phi_2 + .16\,\Phi_3 = 0$$

$$0.85\,\Delta^2\Phi_2 - (0.025 + 0.05)\Phi_2 + 0.06\,\Phi_1 = 0$$

$$0.39\,\Delta^2\Phi_3 - 0.13\,\Phi_3 + 0.05\,\Phi_2 = 0$$

Let us divide the region I into 30 equal intervals, the regions II and III into 20 intervals and region IV into 4 intervals. The mesh-points in the radial direction will be numbered as shown in the figure below.



Let us assume that the axial buckling BH2 = $1.56 * 10^{-3} cm^2$; we shall use poison search in all fissionable regions, ICP = 4, the microscopic absorption cross-section of the poison material σ = 2109 bn, and this will be the only case to be treated. The power output of the reactor is 2441 MW.

OVREL	CONV	PREC	BH2	SCP	POW
1.9E - 01	1.E - 02	1.E - 04	156.E - 05	2109.E 00	2441.E + 06

N_1	N_2	N_3	N_4	ICP	ICC
30	20	20	04	04	0

2, 3, 4th Cards:

The second card carries physical data for the first region--group 1, the third those for group 2, the fourth for group 3. Data are read in the following order (the symbols are self-explanatory; means $\frac{\text{watts}}{\text{fission}}$).

$$D_j \quad \Sigma_{aj} \quad \Sigma_{r_1 j \to j+1} \quad (\nu\Sigma_f)_j \quad (\Sigma_f)_j$$

2nd:	17.E - 1	4.E - 3	6.E - 2	43.E - 2	93.E - 15
3rd:	85.E - 2	25.E - 3	5.E - 2	1.E - 2	19.E - 14
4th:	39.E - 2	13.E - 2	0.E + 0	16.E - 2	21.E - 13

Other 6 cards carry the similar data for regions II and III.

11, 12, 13th Cards:

These cards carry the data for the outer non-fissionable region in order of groups 1, 2, 3. These data are

$$D_j \quad \Sigma_{aj} \quad \Sigma_{S\ j\to j+1}$$

Let the reflector have the following data in order of groups 1, 2, 3

11th:	19.E - 1	36.E - 5	26.E - 3
12th:	92.E - 2	57.E - 5	28.E - 3
13th:	31.. - 2	85.E - 4	0.E 0

14th Card:

This card carries outer radii of regions with increasing order

R_2	R_3	R_4	R_5
877.E - 1	124.E 0	152.E 0	159.E 0

15th Card:

The value carried by this card is the increment of the multiplier adjusting the poison concentration at early stages of control search.

PP

0.05

9.15 Rules for Card Punching

The format of data read is fixed: real variables are read with the format E 10.0, the integer ones with the format I2 with one blank space separating them. On the last card PP, variable is read with the format F5.3.

FORTRAN IV G LEVEL 21 MAIN DATE = 74327 12/56/19

```
                C       MAIN PROGRAM                                                                    A   1
                C       PROGRAM WANDIC                                                                  A   2
                C                                                                                       A   3
                C                                                                                       A   4
                C       THE PROGRAM SOLVES THE THREE-GROUP DIFFUSION EQUATIONS                          A   5
                C       FOR A CYLINDRICAL REACTOR CONSISTING OF THREE FUELED REGIONS                    A   6
                C       AND A REFLECTOR                                                                 A   7
                C                                                                                       A   8
                C                                                                                       A   9
                C       INPUT-MEANING OF SYMBOLS                                                        A  10
                C                                                                                       A  11
                C       NINT...NUMBER OF INTERVALS FOR EACH REGION                                      A  12
                C       OVREL...OVERRELAXATION FACTOR                                                   A  13
                C       CONV...PRECISION FOR THE POINTWISE FLUX CONVERGENCE                             A  14
                C       X...MULTIPLIER FOR THE CONTROL SEARCH PARAMETER                                 A  15
                C       D...DIFFUSION COEFFICIENT                                                       A  16
                C       SCA...MACROSCOPIC ABSORPTION CROSS-SECTION                                      A  17
                C       XNF...MACROSCOPIC FISSION CROSS-SECTION*NU                                      A  18
                C       XKF...MACROSCOPIC FISSION CROSS-SECTION*KAPPA                                   A  19
                C       SR...SCATTERING CROSS-SECTION INTO THE LOWER ADJACENT GROUP                     A  20
                C       BH2...TRANSVERSE BUCKLING                                                       A  21
                C       RR...OUTER RADIUS OF THE REGIONS 1,2,3,4                                        A  22
                C       POW...POWER OUTPUT OF THE REACTOR                                               A  23
                C       SCP...MICROSCOPIC CROSS-SECTION OF THE CONTROL POISON                           A  24
                C       ICP...COTROL PARAMETER FOR THE POISON SEARCH                                    A  25
                C       1...REGION 1                                                                    A  26
                C       2...REGION 2                                                                    A  27
                C       3...REGION 3                                                                    A  28
                C       4...ALL FUELED REGIONS                                                          A  29
                C       5...REGIONS 1&2                                                                 A  30
                C       6...REGIONS 2&3                                                                 A  31
                C       ICC...PROGRAM CONTROL INDICATING THE NUMBER OF CASES                            A  32
                C             POSITIVE INTEGER...SEVERAL CASES TO BE TREATED                            A  33
                C             0...ONLY ONE CASE                                                         A  34
                C                                                                                       A  35
                C                                                                                       A  36
                C       LIMITATIONS OF THE CODE                                                         A  37
                C                                                                                       A  38
                C       1ST:NINT(K) MUST BE EVEN NUMBER                                                 A  39
                C       2ND: TOTAL NUMBER OF MESH-POINTS BE LESS THAN 301                               A  40
                C                                                                                       A  41
    0001                SUBROUTINE PLOT (LI,N,LP)                                                       A  42
    0002                REAL MX,MN,PRNT(6,9),DISP(6),DY,X(300),Y(3,300),H(4)                           A  43
    0003                INTEGER LI,LP,PT,STRG(101),BLK,PER(21),AST,I,N,NINT(4)                          A  44
    0004                COMMON Y,H,NINT                                                                 A  45
    0005                DATA PRNT/4HFAST,4H FLU,4HX - ,4HGROU,4HP 1 ,1H ,4HREGO,4HNANC,4HE              A  46
                       1 FL,4HUX -,4HGROU,4HP 2 ,4HSLOW,4H FLU,4HX - ,4HGROU,4HP 3 ,1H ,4H           A  47
                       2GROU,4HP 1 ,1H ,1H ,1H ,1H ,4HGROU,4HP 2 ,1H ,1H ,1H ,1H ,4HGROU,4          A  48
                       3HP 3 ,1H ,1H ,1H ,1H ,4HGROU,4HP 1 ,4H/ GR,4HOUP ,4H3   ,1H ,4HGRO           A  49
                       4U,4HP 2 ,4H/ GR,4HOUP ,4H3   ,1H ,4HGROU,4HP 1 ,4H/ GR,4HOUP ,4H2           A  50
                       5  ,1H /,8LK,AST/1H ,1H*/,PER/21*'.'/                                        A  51
    0006                DO 1 I=1,101                                                                    A  52
    0007          1     STRG(I)=BLK                                                                     A  53
                C                                                                                       A  54
                C       CALCULATION OF RADII CORRESPONDING TO THE MESH-POINTS                           A  55
                C                                                                                       A  56
    0008                X(1)=0.0                                                                        A  57
    0009                K=1                                                                             A  58
```

FORTRAN IV G LEVEL 21 PLOT DATE = 74327 12/56/19

```
0010              DO 2 I=2,N                                                A  59
0011              X(I)=X(I-1)+H(K)                                          A  60
0012              IF (I.EQ.NINT(K)) K=K+1                                   A  61
0013         2    CONTINUE                                                  A  62
0014              WRITE (6,9) (PRNT(I,LP),I=1,6)                            A  63
0015              MN=Y(LI,1)                                                A  64
0016              MX=MN                                                     A  65
0017              DO 6 I=2,N                                                A  66
0018              IF (MX-Y(LI,I)) 3,4,4                                     A  67
0019         3    MX=Y(LI,I)                                                A  68
0020              GO TO 6                                                   A  69
0021         4    IF (MN-Y(LI,I)) 6,6,5                                     A  70
0022         5    MN=Y(LI,I)                                                A  71
0023         6    CONTINUE                                                  A  72
0024              DY=(MX-MN)/100                                            A  73
0025              DO 7 I=1,6                                                A  74
0026         7    DISP(I)=MN+(I-1)*20*DY                                    A  75
0027              WRITE (6,10) DISP                                         A  76
0028              WRITE (6,11) (PER(I),I=1,21)                              A  77
0029              DO 8 I=1,N                                                A  78
0030              PT=(Y(LI,I)-MN)/DY+1.5                                    A  79
0031              STRG(PT)=AST                                              A  80
0032              WRITE (6,12) X(I),STRG                                    A  81
0033         8    STRG(PT)=BLK                                              A  82
0034              RETURN                                                    A  83
                  C                                                         A  84
0035         9    FORMAT (1H1,45X,7HPLOT OF,1X,6A4,//,57X,6HZ-AXIS)         A  85
0036         10   FORMAT (11X,6(E10.3,10X))                                 A  86
0037         11   FORMAT (16X,21(A1,4X),/,7H R-AXIS)                        A  87
0038         12   FORMAT (E11.3,5X,101A1)                                   A  88
0039              END                                                       A  89
```

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 74327        12/56/19

                C     INTEGRATION SIMPSON FOR N POINTS. N MUST BE EVEN.                  B   1
                C     N MUST BE WITHIN 4 AND 100                                         B   2
0001                  FUNCTION SIMP (DX,XX,N,J1)                                       B   3
0002                  DIMENSION XX(100), DX(4)                                         B   4
0003                  SIMP=XX(1)+XX(N)+4.*XX(N-1)                                      B   5
0004                  J=(N-3)/2                                                        B   6
0005                  DO 1 I=1,J                                                       B   7
0006            1     SIMP=SIMP+4.*XX(2*I)+2.*XX(2*I+1)                                B   8
0007                  SIMP=SIMP*DX(J1)/3.                                              B   9
0008                  RETURN                                                           B  10
0009                  END                                                              B  11
```

FORTRAN IV G LEVEL 21 MAIN DATE = 74327 12/56/19

```
                C     ACCELERATED 'REGULA FALSI'                                C  1
                C                                                               C  2
                C                                                               C  3
0001                  SUBROUTINE ZERO (A1,A2,F1,F2,A10,A20,DF1,DF2,RAD)         C  4
0002            1     RAD=A2-F2*(A2-A1)/(F2-F1)                                 C  5
0003                  VARA=A2-F2*(A2-A1)/(F2-F1)                                C  6
0004                  HH=ABS(A20-A10)                                           C  7
0005                  H1=ABS(VARA-A10)                                          C  8
0006                  H2=ABS(VARA-A20)                                          C  9
0007                  IF (H1-H2) 2,8,3                                          C 10
0008            2     TEMP=H2                                                   C 11
0009                  L=2                                                       C 12
0010                  GO TO 4                                                   C 13
0011            3     TEMP=H1                                                   C 14
0012                  L=1                                                       C 15
0013            4     IF (TEMP-HH) 8,5,5                                        C 16
0014            5     GO TO (6,7), L                                            C 17
0015            6     A2=A20                                                    C 18
0016                  F2=DF2                                                    C 19
0017                  GO TO 1                                                   C 20
0018            7     A2=A10                                                    C 21
0019                  F2=DF1                                                    C 22
0020                  GO TO 1                                                   C 23
0021            8     RETURN                                                    C 24
0022                  END                                                       C 25
```

```
FORTRAN IV G LEVEL  21                  MAIN                DATE = 74327          12/56/19

                C       ENTRY OF DATA AND DIMENSIONS OF ARRAYS                                  D    1
 0001                   DIMENSION NINT(4), RR(5), H(4), EPS(30), SCA0(3,3)                      D    2
 0002                   DIMENSION SCA(3,4), SR(3,4), D(3,4), XNF(3,3), XKF(3,3)                 D    3
 0003                   DIMENSION SANT(300), DFMAX(3), FS(300), SUM(300), SDS(300), AIDD(3      D    4
                       1,300)                                                                   D    5
 0004                   DIMENSION ALFA(300), BETA(300), S(300), FLUX(3,300), GX(100), FPR(      D    6
                       13)                                                                      D    7
 0005                   COMMON AIDD,H,NINT                                                      D    8
 0006          1        READ (5,142) OVREL,CONV,PREC,BH2,SCP,POW,NINT,ICP,ICC                   D    9
 0007                   READ (5,143) ((D(I,K),SCA(I,K),SR(I,K),XNF(I,K),XKF(I,K),I=1,3),K=      D   10
                       11,3)                                                                    D   11
 0008                   READ (5,144) (D(I,4),SCA(I,4),SR(I,4),I=1,3)                            D   12
 0009                   READ (5,145) (RR(K),K=2,5)                                              D   13
 0010                   READ (5,146) PP                                                         D   14
                C                                                                              D   15
                C       PRINTING OF DATA                                                       D   16
                C                                                                              D   17
 0011                   RR(1)=0.0                                                               D   18
 0012                   WRITE (6,147)                                                           D   19
 0013                   WRITE (6,148)                                                           D   20
 0014                   WRITE (6,149) (RR(L),L=1,5)                                             D   21
 0015                   WRITE (6,150) NINT,OVREL,PREC,CONV                                      D   22
 0016                   WRITE (6,151) BH2,SCP                                                   D   23
 0017                   WRITE (6,152) ((SCA(I,K),I=1,3),K=1,4)                                  D   24
 0018                   WRITE (6,153) ((D(I,K),I=1,3),K=1,4)                                    D   25
 0019                   WRITE (6,154) ((SR(I,K),I=1,3),K=1,4)                                   D   26
 0020                   WRITE (6,155) ((XNF(I,K),I=1,3),K=1,3)                                  D   27
 0021                   WRITE (6,156) ((XKF(I,K),I=1,3),K=1,3)                                  D   28
 0022                   WRITE (6,157) POW                                                       D   29
 0023                   WRITE (6,158)                                                           D   30
                C                                                                              D   31
                C       NUMBERING OF MESH-POINTS                                               D   32
                C                                                                              D   33
 0024                   PI=3.14159265                                                           D   34
 0025                   CF=1.6021E-13                                                           D   35
 0026                   TEMP=1.0                                                                D   36
 0027                   ITER=1                                                                  D   37
 0028                   NIT=1                                                                   D   38
 0029                   NINT(1)=NINT(1)+1                                                       D   39
 0030                   N1=NINT(1)                                                              D   40
 0031                   DO 2 K=2,4                                                              D   41
 0032          2        NINT(K)=NINT(K)+NINT(K-1)                                               D   42
 0033                   N2=NINT(2)                                                              D   43
 0034                   N3=NINT(3)                                                              D   44
 0035                   N3M1=N3-1                                                               D   45
 0036                   N4=NINT(4)                                                              D   46
 0037                   N4M1=N4-1                                                               D   47
 0038                   XP=1.                                                                   D   48
 0039                   JJ=1                                                                    D   49
 0040                   DO 3 K=1,4                                                              D   50
 0041                   DO 3 I=1,3                                                              D   51
 0042          3        SCA(I,K)=SCA(I,K)+SR(I,K)+BH2*D(I,K)                                    D   52
 0043                   DO 4 K=1,3                                                              D   53
 0044          4        SCA0(3,K)=SCA(3,K)                                                      D   54
 0045                   DO 5 N=1,N4M1                                                           D   55
 0046                   FS(N)=0.0                                                               D   56
 0047          5        SUM(N)=0.0                                                              D   57
                C                                                                              D   58
```

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 74327        12/56/19

                C     CALCULATION OF H(K)                                              D  59
                C                                                                      D  60
 0048                 DO 8 K=1,4                                                       D  61
 0049                 IF (K-1) 8,6,7                                                   D  62
 0050           6     TEMP=NINT(1)-1                                                   D  63
 0051                 GO TO 8                                                          D  64
 0052           7     TEMP=NINT(K)-NINT(K-1)                                           D  65
 0053           8     H(K)=(RR(K+1)-RR(K))/TEMP                                        D  66
                C                                                                      D  67
                C     POISON CONTROL BLOCK                                             D  68
                C                                                                      D  69
 0054           9     GO TO (10,10,10,11,12,13), ICP                                   D  70
 0055           10    SCA(3,ICP)=SCAO(3,ICP)*XP                                        D  71
 0056                 GO TO 16                                                         D  72
 0057           11    KF=1                                                             D  73
 0058                 KL=3                                                             D  74
 0059                 GO TO 14                                                         D  75
 0060           12    KF=1                                                             D  76
 0061                 KL=2                                                             D  77
 0062                 GO TO 14                                                         D  78
 0063           13    KF=2                                                             D  79
 0064                 KL=3                                                             D  80
 0065           14    DO 15 K=KF,KL                                                    D  81
 0066           15    SCA(3,K)=SCAO(3,K)*XP                                            D  82
 0067                 JJ=1                                                             D  83
                C                                                                      D  84
                C     GENERATION OF THE INITIAL FAST SOURCE                            D  85
                C                                                                      D  86
 0068           16    S(1)=1./(RR(4)*RR(4)*PI)                                         D  87
 0069                 ITC=1                                                            D  88
 0070                 SANT(1)=S(1)                                                     D  89
 0071                 DO 21 N=2,N4                                                     D  90
 0072                 IF (N-N3) 18,19,17                                               D  91
 0073           17    S(N)=0.0                                                         D  92
 0074                 GO TO 21                                                         D  93
 0075           18    S(N)=S(1)                                                        D  94
 0076                 GO TO 20                                                         D  95
 0077           19    S(N3)=S(1)*H(3)/(H(3)+H(4))                                      D  96
 0078           20    SANT(N)=S(N)                                                     D  97
 0079           21    CONTINUE                                                         D  98
 0080                 FMANT=1.0                                                        D  99
                C                                                                      D 100
                C                                                                      D 101
                C     CALCULATION OF FLUXES                                            D 102
                C                                                                      D 103
 0081           22    DO 58 I=1,3                                                      D 104
 0082                 TEMP=H(1)*H(1)*SCA(I,1)+4.*D(I,1)                                D 105
 0083                 ALFA(2)=4.*D(I,1)/TEMP                                           D 106
 0084                 BETA(2)=S(1)*H(1)*H(1)/TEMP                                      D 107
 0085                 R=0.0                                                            D 108
 0086                 K=1                                                              D 109
 0087                 DO 26 N=2,N4M1                                                   D 110
 0088                 IF (N-NINT(K)) 23,24,23                                          D 111
 0089           23    R=R+H(K)                                                         D 112
 0090                 AN=(1.+H(K)/(2.*R))*D(I,K)/(H(K)*H(K))                           D 113
 0091                 CN=(1.-H(K)/(2.*R))*D(I,K)/(H(K)*H(K))                           D 114
 0092                 BN=AN+CN+SCA(I,K)                                                D 115
 0093                 GO TO 25                                                         D 116
```

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 74327        12/56/19

0094          24    K=K+1                                                          D 117
0095                R=RR(K)                                                        D 118
0096                TEMP=(H(K-1)+H(K))*.5                                          D 119
0097                AN=(1.+H(K)/(2.*R))*D(I,K)/(H(K)*TEMP)                         D 120
0098                CN=(1.-H(K-1)/(2.*R))*D(I,K-1)/(H(K-1)*TEMP)                   D 121
0099                BN=AN+CN+(SCA(I,K)*H(K)+SCA(I,K-1)*H(K-1))/(H(K)+H(K-1))       D 122
0100          25    TEMP=BN-CN*ALFA(N)                                             D 123
0101                ALFA(N+1)=AN/TEMP                                              D 124
0102          26    BETA(N+1)=(S(N)+CN*BETA(N))/TEMP                               D 125
0103                BM=CN*(3.+H(4)/(1.066*D(I,4)))-AN                              D 126
0104                CM=4.*CN-BN                                                    D 127
0105                GO TO (28,27), ITER                                            D 128
0106          27    TEMP=FLUX(I,N4)                                                D 129
0107          28    FLUX(I,N4)=(S(N4M1)+CM*BETA(N4))/(BM-CM*ALFA(N4))              D 130
0108                GO TO (30,29), ITER                                            D 131
0109          29    DFMAX(I)=ABS((TEMP-FLUX(I,N4))/TEMP)                           D 132
0110          30    DO 35 N=1,N4M1                                                 D 133
0111                L=N4-N                                                         D 134
0112                GO TO (32,31), ITER                                            D 135
0113          31    TEMP=FLUX(I,L)                                                 D 136
0114          32    FLUX(I,L)=ALFA(L+1)*FLUX(I,L+1)+BETA(L+1)                      D 137
0115                GO TO (35,33), ITER                                            D 138
0116          33    DFMAX(I)=ABS((TEMP-FLUX(I,L))/TEMP)                            D 139
0117                IF (DFMAX(I)-TEMP) 34,35,35                                    D 140
0118          34    DFMAX(I)=TEMP                                                  D 141
0119          35    CONTINUE                                                       D 142
              C                                                                    D 143
              C     CALCULATION OF SOURCE FOR THE FOLLOWING GROUP                  D 144
              C                                                                    D 145
0120                K=1                                                            D 146
0121                DO 58 N=1,N4M1                                                 D 147
0122                IF (N.GT.NINT(3)) GO TO 40                                     D 148
0123                IF (N-NINT(K)) 36,40,36                                        D 149
0124          36    GO TO (38,38,37), I                                            D 150
0125          37    SDS(N)=0.0                                                     D 151
0126                GO TO 39                                                       D 152
0127          38    SDS(N)=SR(I,K)*FLUX(I,N)                                       D 153
0128          39    FS(N)=XNF(I,K)*FLUX(I,N)                                       D 154
0129                GO TO 53                                                       D 155
0130          40    K=K+1                                                          D 156
0131                IF (K-4) 45,41,50                                              D 157
0132          41    GO TO (43,43,42), I                                            D 158
0133          42    SDS(N)=0.0                                                     D 159
0134                TEMP1=0.0                                                      D 160
0135                GO TO 44                                                       D 161
0136          43    SDS(N)=SR(I,K)*FLUX(I,N)                                       D 162
0137                TEMP1=SR(I,K-1)*FLUX(I,N)                                      D 163
0138          44    TEMP2=XNF(I,K-1)*FLUX(I,N)                                     D 164
0139                FS(N)=0.0                                                      D 165
0140                GO TO 49                                                       D 166
0141          45    GO TO (47,47,46), I                                            D 167
0142          46    SDS(N)=0.0                                                     D 168
0143                TEMP1=0.0                                                      D 169
0144                GO TO 48                                                       D 170
0145          47    SDS(N)=SR(I,K)*FLUX(I,N)                                       D 171
0146                TEMP1=SR(I,K-1)*FLUX(I,N)                                      D 172
0147          48    FS(N)=XNF(I,K)*FLUX(I,N)                                       D 173
0148                TEMP2=XNF(I,K-1)*FLUX(I,N)                                     D 174
```

FORTRAN IV G LEVEL 21 MAIN DATE = 74327 12/56/19

```
0149        49    TEMP=H(K)+H(K-1)                                                    D 175
0150              SDS(N)=(SDS(N)*H(K)+TEMP1*H(K-1))/TEMP                              D 176
0151              FS(N)=(FS(N)*H(K)+TEMP2*H(K-1))/TEMP                                D 177
0152              GO TO 53                                                            D 178
0153        50    GO TO (52,52,51), I                                                 D 179
0154        51    SDS(N)=0.0                                                          D 180
0155              GO TO 54                                                            D 181
0156        52    SDS(N)=SR(I,4)*FLUX(I,N)                                            D 182
0157              GO TO 54                                                            D 183
0158        53    SUM(N)=SUM(N)+FS(N)                                                 D 184
0159        54    GO TO (56,56,55), I                                                 D 185
0160        55    IF (N.GT.NINT(3)) GO TO 57                                          D 186
0161              S(N)=SUM(N)                                                         D 187
0162              SUM(N)=0.0                                                          D 188
0163              GO TO 58                                                            D 189
0164        56    S(N)=SDS(N)                                                         D 190
0165              GO TO 58                                                            D 191
0166        57    S(N)=0.0                                                            D 192
0167        58    CONTINUE                                                            D 193
              C                                                                       D 194
              C     INTEGRATION OF THE SOURCE                                         D 195
              C                                                                       D 196
0168              FMULT=S(N3)*RR(4)*H(4)/3.                                           D 197
0169              DO 63 K=1,3                                                         D 198
0170              GO TO (59,60,60), K                                                 D 199
0171        59    L=0                                                                 D 200
0172              GO TO 61                                                            D 201
0173        60    L=NINT(K-1)-1                                                       D 202
0174        61    M=NINT(K)-L                                                         D 203
0175              R=RR(K)                                                             D 204
0176              DO 62 N=1,M                                                         D 205
0177              ITEMP=N+L                                                           D 206
0178              GX(N)=S(ITEMP)*R                                                    D 207
0179        62    R=R+H(K)                                                            D 208
0180        63    FMULT=FMULT+SIMP(H,GX,M,K)                                          D 209
0181              FMULT=FMULT*2.*PI                                                   D 210
0182              WRITE (6,159) FMULT                                                 D 211
0183              IF (ABS(FMULT-FMANT)/FMULT-PREC/5.) 65,64,64                        D 212
              C                                                                       D 213
              C     PREPARATION OF ITERATIONS                                         D 214
              C                                                                       D 215
0184        64    RPSP=0.0                                                            D 216
0185              DO 66 N=1,N3                                                        D 217
0186              S(N)=S(N)/FMULT                                                     D 218
0187              EMAX=ABS((S(N)-SANT(N))/SANT(N))                                    D 219
0188              IF (EMAX-RPSP) 66,66,65                                             D 220
0189        65    RPSP=EMAX                                                           D 221
0190        66    CONTINUE                                                            D 222
0191              EPS(JJ)=RPSP                                                        D 223
0192              IF (JJ-20) 72,67,67                                                 D 224
0193        67    IF (ABS(EPS(10)/EPS(20))-1.5) 68,71,71                              D 225
0194        68    IF (ABS(EPS(20)/EPS(19)*(1.+ABS(EPS(19))))-1.) 71,69,69             D 226
0195        69    GO TO (70,71), ITER                                                 D 227
0196        70    OVREL=OVREL-0.1                                                     D 228
0197        71    JJ=1                                                                D 229
0198        72    DO 84 N=1,N3                                                        D 230
0199              Q=S(N)/SANT(N)-1.                                                   D 231
0200              IF (Q) 73,74,74                                                     D 232
```

37 A

FORTRAN IV G LEVEL 21 MAIN DATE = 74327 12/56/19

```
0201        73    K1=1                                                    D 233
0202              GO TO 75                                                D 234
0203        74    K1=2                                                    D 235
0204        75    Q=ABS(Q)*CVREL                                          D 236
0205              IF (Q-0.1) 77,76,76                                     D 237
0206        76    Q=1.0/EXP(Q)                                            D 238
0207              GO TO 80                                                D 239
0208        77    IF (Q-.001) 79,78,78                                    D 240
0209        78    Q=(1.-Q/2.)/(1.+Q/2.)                                   D 241
0210              GO TO 80                                                D 242
0211        79    Q=1.-Q                                                  D 243
0212        80    GO TO (81,82), K1                                       D 244
0213        81    S(N)=SANT(N)*Q                                          D 245
0214              GO TO 83                                                D 246
0215        82    S(N)=SANT(N)*(2.-Q)                                     D 247
0216        83    SANT(N)=S(N)                                            D 248
0217        84    CONTINUE                                                D 249
0218              FMANT=FMULT                                             D 250
0219              JJ=JJ+1                                                 D 251
0220              ITC=ITC+1                                               D 252
0221              IF (ITC.GT.400) GO TO 140                               D 253
0222              GO TO 22                                                D 254
0223        85    GO TO (89,86), ITER                                     D 255
0224        86    DFMM=0.0                                                D 256
0225              DO 88 I=1,3                                             D 257
0226              IF (DFMAX(I)-DFMM) 88,88,87                             D 258
0227        87    DFMM=DFMAX(I)                                           D 259
0228        88    CONTINUE                                                D 260
0229              IF (DFMM-CONV) 89,64,64                                 D 261
0230        89    FME=1.                                                  D 262
0231              DFMUL=FMULT-FME                                         D 263
0232              WRITE (6,160) XP,FMULT                                  D 264
0233              IF (XP.EQ.1.0) EIGEN=FMULT                              D 265
0234              IF (ABS(DFMUL)-PREC) 104,90,90                          D 266
0235        90    GO TO (91,92,99,103), NIT                               D 267
0236        91    DFM1=DFMUL                                              D 268
0237              NIT=2                                                   D 269
0238              GO TO 93                                                D 270
0239        92    IF (DFMUL*DFM1) 95,104,93                               D 271
0240        93    IF (DFMUL) 94,104,94                                    D 272
0241        94    X1=XP                                                   D 273
0242              XP=XP+PP*DFMUL/ABS(DFMUL)
0243              DFM1=DFMUL
0244              GO TO 9                                                 D 275
0245        95    IF (DFMUL) 96,104,97                                    D 276
0246        96    DF2=DFM1                                                D 277
0247              DF1=DFMUL                                               D 278
0248              A20=X1                                                  D 279
0249              A10=XP                                                  D 280
0250              XP=X1-DFM1*(X1-XP)/(DFM1-DFMUL)                         D 281
0251              GO TO 98                                                D 282
0252        97    DF2=DFMUL                                               D 283
0253              DF1=DFM1                                                D 284
0254              A20=XP                                                  D 285
0255              A10=X1                                                  D 286
0256              XP=XP-DFMUL*(XP-X1)/(DFMUL-DFM1)                        D 287
0257        98    NIT=3                                                   D 288
0258              X1=XP                                                   D 289
```

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 74327        12/56/19

0259                    DFM1=DFMUL                                                  D 290
0260                    GO TO 9                                                     D 291
0261          99        NIT=4                                                       D 292
0262                    DFM1=DFMUL                                                  D 293
0263                    X1=XP                                                       D 294
0264                    IF (DFMUL) 100,104,101                                      D 295
0265          100       XP=X1-DFM1*(A20-X1)/(DF2-DFM1)                              D 296
0266                    GO TO 102                                                   D 297
0267          101       XP=X1-DFM1*(X1-A10)/(DFM1-DF1)                              D 298
0268          102       XANT=XP                                                     D 299
0269                    GO TO 9                                                     D 300
0270          103       CALL ZERO (X1,XANT,DFM1,DFMUL,A10,A20,DF1,DF2,XP)           D 301
0271                    X1=XANT                                                     D 302
0272                    XANT=XP                                                     D 303
0273                    DFM1=DFMUL                                                  D 304
0274                    GO TO 9                                                     D 305
0275          104       GO TO (105,106), ITER                                       D 306
0276          105       ITER=2                                                      D 307
0277                    WRITE (6,161) ITER                                          D 308
0278                    GO TO 64                                                    D 309
              C                                                                     D 310
              C     PREPARATION OF OUTPUT                                         D 311
              C     CALCULATION OF POWER NORMALIZED FLUXES                        D 312
              C                                                                     D 313
0279          106       FP=0.0                                                      D 314
0280                    DO 107 N=1,N3                                               D 315
0281          107       SUM(N)=0.0                                                  D 316
0282                    K=1                                                         D 317
0283                    DO 110 I=1,3                                                D 318
0284                    DO 110 N=1,N3M1                                             D 319
0285                    IF (N-NINT(K)) 108,109,108                                  D 320
0286          108       FS(N)=XKF(I,K)*FLUX(I,N)                                    D 321
0287                    GO TO 110                                                   D 322
0288          109       K=K+1                                                       D 323
0289                    TEMP=XKF(I,K-1)*FLUX(I,N)                                   D 324
0290                    FS(N)=XKF(I,K)*FLUX(I,N)                                    D 325
0291                    FS(N)=(FS(N)*H(K)+TEMP*H(K-1))/(H(K)+H(K-1))                D 326
0292          110       SUM(N)=SUM(N)+FS(N)                                         D 327
0293                    TEMP=H(3)/(H(3)+H(4))                                       D 328
0294                    DO 111 I=1,3                                                D 329
0295          111       SUM(N3)=SUM(N3)+XKF(I,3)*FLUX(I,N3)*TEMP                    D 330
0296                    DO 119 K=1,3                                                D 331
0297                    GO TO (112,113,113), K                                      D 332
0298          112       L=0                                                         D 333
0299                    GO TO 114                                                   D 334
0300          113       L=NINT(K-1)-1                                               D 335
0301          114       M=NINT(K)-L                                                 D 336
0302                    R=RR(K)                                                     D 337
0303                    DO 115 N=1,M                                                D 338
0304                    ITEMP=N+L                                                   D 339
0305                    GX(N)=SUM(ITEMP)*R                                          D 340
0306          115       R=R+H(K)                                                    D 341
0307                    FP=FP+SIMP(H,GX,M,K)                                        D 342
0308                    IF (K.EQ.3) FP=FP+SUM(N3)*RR(4)*H(4)/3.                     D 343
0309                    GO TO (116,117,118), K                                      D 344
0310          116       FPR(K)=FP                                                   D 345
0311                    GO TO 119                                                   D 346
0312          117       FPR(K)=(FP-FPR(K-1))                                        D 347
```

FORTRAN IV G LEVEL 21 MAIN DATE = 74327 12/56/19

```
0313              GO TO 119                                                  D 348
0314        118   FPR(K)=(FP-FPR(K-1)-FPR(K-2))                              D 349
0315        119   CONTINUE                                                   D 350
0316              FP=0.0                                                     D 351
0317              DO 120 K=1,3                                               D 352
0318              FPR(K)=2.*PI*FPR(K)                                        D 353
0319        120   FP=FP+FPR(K)                                               D 354
0320              GAM=POW/FP                                                 D 355
0321              TEMP=PI/SQRT(BH2)                                          D 356
0322              GAM=GAM/TEMP                                               D 357
0323              WRITE (6,162)                                              D 358
0324              WRITE (6,163) (RR(L),L=1,5)                                D 359
0325              WRITE (6,164) EIGEN                                        D 360
0326              WRITE (6,165)                                              D 361
0327              GO TO (121,121,121,122,123,124), ICP                       D 362
0328        121   WRITE (6,166) ICP                                          D 363
0329              GO TO 125                                                  D 364
0330        122   WRITE (6,167)                                              D 365
0331              GO TO 125                                                  D 366
0332        123   WRITE (6,168)                                              D 367
0333              GO TO 125                                                  D 368
0334        124   WRITE (6,169)                                              D 369
0335        125   DO 126 K=1,3                                               D 370
0336        126   SCA(3,K)=SCA(3,K)-D(3,K)*BH2                               D 371
0337              GO TO (127,128,129,127,127,128), ICP                       D 372
0338        127   K=1                                                        D 373
0339              GO TO 130                                                  D 374
0340        128   K=2                                                        D 375
0341              GO TO 130                                                  D 376
0342        129   K=3                                                        D 377
0343        130   TEMP=SCA(3,K)-SCAU(3,K)                                    D 378
0344              WRITE (6,170) TEMP                                         D 379
0345              TEMP=TEMP/SCP*1.E+24                                       D 380
0346              WRITE (6,171) TEMP                                         D 381
0347              WRITE (6,172)                                              D 382
0348              WRITE (6,173) (FLUX(1,N),N=1,N4)                           D 383
0349              WRITE (6,174) (FLUX(2,N),N=1,N4)                           D 384
0350              WRITE (6,175) (FLUX(3,N),N=1,N4)                           D 385
                  C                                                          D 386
                  C     CALCULATION OF POWER NORMALIZED FLUXES               D 387
                  C                                                          D 388
0351              DO 131 I=1,3                                               D 389
0352              DO 131 N=1,N4                                              D 390
0353              FLUX(I,N)=FLUX(I,N)*GAM                                    D 391
0354        131   AIDD(I,N)=FLUX(I,N)                                        D 392
0355              WRITE (6,176)                                              D 393
0356              WRITE (6,177) (AIDD(1,N),N=1,N4)                           D 394
0357              WRITE (6,178) (AIDD(2,N),N=1,N4)                           D 395
0358              WRITE (6,179) (AIDD(3,N),N=1,N4)                           D 396
0359              DO 132 LI=1,3                                              D 397
0360              LP=LI                                                      D 398
0361              CALL PLOT (LI,N4,LP)                                       D 399
0362        132   CONTINUE                                                   D 400
0363              WRITE (6,180)                                              D 401
0364              DO 133 I=1,3                                               D 402
0365              TEMP=FLUX(I,1)                                             D 403
0366              DO 133 N=1,N4                                              D 404
0367        133   AIDD(I,N)=FLUX(I,N)/TEMP                                   D 405
```

40

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 74327          12/56/19

0368                  WRITE (6,181) (AIDD(1,N),N=1,N4)                                  D 406
0369                  WRITE (6,182) (AIDD(2,N),N=1,N4)                                  D 407
0370                  WRITE (6,183) (AIDD(3,N),N=1,N4)                                  D 408
0371                  DO 134 LI=1,3                                                     D 409
0372                  LP=LI+3                                                           D 410
0373                  CALL PLOT (LI,N4,LP)                                              D 411
0374            134   CONTINUE                                                          D 412
0375                  DO 135 I=1,2                                                      D 413
0376                  DO 135 N=1,N4                                                     D 414
0377            135   AIDD(I,N)=FLUX(I,N)/FLUX(3,N)                                     D 415
0378                  WRITE (6,184)                                                     D 416
0379                  WRITE (6,185) (AIDD(1,N),N=1,N4)                                  D 417
0380                  WRITE (6,186) (AIDD(2,N),N=1,N4)                                  D 418
0381                  DO 136 LI=1,2                                                     D 419
0382                  LP=6+LI                                                           D 420
0383                  CALL PLOT (LI,N4,LP)                                              D 421
0384            136   CONTINUE                                                          D 422
0385                  DO 137 N=1,N4                                                     D 423
0386            137   AIDD(1,N)=FLUX(1,N)/FLUX(2,N)                                     D 424
0387                  WRITE (6,187) (AIDD(1,N),N=1,N4)                                  D 425
0388                  CALL PLOT (1,N4,9)                                                D 426
                C                                                                       D 427
                C     CALCULATION OF POWER GENERATED IN EACH REGION                     D 428
                C                                                                       D 429
0389                  DO 138 K=1,3                                                      D 430
0390                  TEMP=PI/SQRT(BH2)                                                 D 431
0391                  FPR(K)=FPR(K)*TEMP*GAM                                            D 432
0392            138   CONTINUE                                                          D 433
0393                  WRITE (6,188) (FPR(K),K=1,3)                                      D 434
0394                  DO 139 K=1,3                                                      D 435
0395                  FPR(K)=FPR(K)/TEMP                                                D 436
0396                  TEMP=PI*(RR(K+1)*RR(K+1)-RR(K)*RR(K))                             D 437
0397                  FPR(K)=FPR(K)/TEMP                                                D 438
0398            139   CONTINUE                                                          D 439
0399                  WRITE (6,189) (FPR(K),K=1,3)                                      D 440
0400                  WRITE (6,190) OVREL                                               D 441
0401                  IF (ICC.GT.0) GO TO 1                                             D 442
0402                  GO TO 141                                                         D 443
0403            140   WRITE (6,191)                                                     D 444
0404            141   STOP                                                              D 445
                C                                                                       D 446
0405            142   FORMAT (6E10.0,6(1X,I2))                                          D 447
0406            143   FORMAT (5E10.0)                                                   D 448
0407            144   FORMAT (3E10.0)                                                   D 449
0408            145   FORMAT (4E10.0)                                                   D 450
0409            146   FORMAT (F5.3)                                                     D 451
0410            147   FORMAT (1H1)                                                      D 452
0411            148   FORMAT (16H PROGRAM WAN DIC,///,26H REGIONS IN ORDER 1,2,3,4,//)  D 453
0412            149   FORMAT (17H RADII OF REGIONS,//,2X,8HREGION 1,4X,8HREGION 2,4X,8HR D 454
                     1EGION 3,4X,8HREGION 4,4X,8HREGION 5,//,2X,5(F8.2,4X))           D 455
0413            150   FORMAT (7H NINT =,4(I2,1X),/,7H OVREL=,F6.2,6X,6H PREC=,E9.2,6X,6H D 456
                     1 CONV=,E9.2)                                                     D 457
0414            151   FORMAT (//,6H BH2 =,E12.5,6X,28H POISON MICRO CROSS-SECTION=,1X,E1 D 458
                     12.5,//)                                                          D 459
0415            152   FORMAT (26H ABSORPTION CROSS-SECTIONS,//,5X,7HGROUP 1,7X,7HGROUP 2 D 460
                     1,7X,7HGROUP 3,/,3(2X,E12.5),/)                                   D 461
0416            153   FORMAT (//,23H DIFFUSION COEFFICIENTS,//,3(2X,E12.5),/)           D 462
0417            154   FORMAT (//,26H TRANSFER CROSS-SECTIONS  ,//,3(2X,E12.5),/)        D 463
```

41

FORTRAN IV G LEVEL 21 MAIN DATE = 74327 12/56/19

```
0418          155    FORMAT (//,23H NU-FISSION              ,//,3(2X,E12.5),/)                                    D 464
0419          156    FORMAT (//,14H KAPPA-FISSION,//,3(2X,E12.5),/)                                               D 465
0420          157    FORMAT (13H POWER (W) = ,E12.5)                                                              D 466
0421          158    FORMAT (1H1)                                                                                 D 467
0422          159    FORMAT (1X,4H  K=,F10.6)                                                                     D 468
0423          160    FORMAT (//,5H XP= ,E12.5,5X,15H EIGENVALUE K =,E12.5)                                        D 469
0424          161    FORMAT (7H ITER= ,I2)                                                                        D 470
0425          162    FORMAT (1H1,8H RESULTS,///)                                                                  D 471
0426          163    FORMAT (17H RADII OF REGIONS,//,2X,8HREGION 1,4X,8HREGION 2,4X,8HR                           D 472
                    1EGION 3,4X,8HREGION 4,4X,8HREGION 5,//,2X,5(F8.2,4X))                                       D 473
0427          164    FORMAT (//,41H EIGENVALUE OF THE UNPOISONED REACTOR K =,E12.5)                               D 474
0428          165    FORMAT (//,49H CONTROL POISON WAS USED IN THE FOLLOWING REGIONS,/)                           D 475
0429          166    FORMAT (9H REGION  ,I2)                                                                      D 476
0430          167    FORMAT (21H ALL FISSION REGIONS )                                                            D 477
0431          168    FORMAT (17H REGIONS 1 AND 2 )                                                                D 478
0432          169    FORMAT (17H REGIONS 2 AND 3 )                                                                D 479
0433          170    FORMAT (//,36H MACRO CROSS-SECTION OF THE POISON= ,E12.5)                                    D 480
0434          171    FORMAT (//,24H POISON CONCENTRATION = ,E12.5)                                                D 481
0435          172    FORMAT (////,28H FLUXES NORMALIZED TO SOURCE)                                                D 482
0436          173    FORMAT (//,19H FAST FLUX-GROUP 1 ,/,5(2X,E12.5))                                             D 483
0437          174    FORMAT (//,24H RESONANCE FLUX-GROUP 2 ,/,5(2X,E12.5))                                        D 484
0438          175    FORMAT (//,19H SLOW FLUX-GROUP 3 ,/,5(2X,E12.5))                                             D 485
0439          176    FORMAT (////,28H FLUXES NORMALIZED TO POWER )                                                D 486
0440          177    FORMAT (//,19H FAST FLUX-GROUP 1 ,/,5(2X,E12.5))                                             D 487
0441          178    FORMAT (//,24H RESONANCE FLUX-GROUP 2 ,/,5(2X,E12.5))                                        D 488
0442          179    FORMAT (//,19H SLOW FLUX-GROUP 3 ,/,5(2X,E12.5))                                             D 489
0443          180    FORMAT (///,16H RELATIVE FLUXES)                                                             D 490
0444          181    FORMAT (//,9H GROUP 1 ,/,5(2X,E12.5))                                                        D 491
0445          182    FORMAT (//,9H GROUP 2 ,/,5(2X,E12.5))                                                        D 492
0446          183    FORMAT (//,9H GROUP 3 ,/,5(2X,E12.5))                                                        D 493
0447          184    FORMAT (///,35H RATIOS OF FLUXES TO THE SLOW FLUX )                                          D 494
0448          185    FORMAT (//,19H GROUP 1 / GROUP 3 ,/,5(2X,E12.5))                                             D 495
0449          186    FORMAT (//,19H GROUP 2 / GROUP 3 ,/,5(2X,E12.5))                                             D 496
0450          187    FORMAT (//,19H GROUP 1 / GROUP 2 ,//,5(2X,E12.5))                                            D 497
0451          188    FORMAT (//,31H POWER OUTPUT IN REGIONS  1,2,3,//,2X,3(E12.5,5X))                             D 498
0452          189    FORMAT (//,42H POWER DENSITY IN REGIONS 1,2,3 (KW/LITER),//,2X,3(E                           D 499
                    112.5,5X))                                                                                   D 500
0453          190    FORMAT (//,33H COMPUTED OVERRELAXATION FACTOR= ,F6.3)                                        D 501
0454          191    FORMAT (22H # OF ITERATIONS > 400)                                                           D 502
0455                 END                                                                                        D 503
```

```
PROGRAM WAN DIC

REGIONS IN ORDER 1,2,3,4,

RADII OF REGIONS

 REGION 1     REGION 2     REGION 3     REGION 4     REGION 5

      0.0         87.70       124.00       152.00       159.00
NINT =30 20 20  4
OVREL=  1.90         PREC= 0.10E-03         CONV= 0.10E-01

BH2 = 0.73800E-04         POISON MICRO CROSS-SECTION=  0.21090E 04

ABSORPTION CROSS-SECTIONS

    GROUP 1         GROUP 2         GROUP 3
  0.35410E-02     0.25680E-01     0.13870E 00

  0.35410E-02     0.25680E-01     0.13870E 00

  0.35410E-02     0.25680E-01     0.13870E 00

  0.36220E-03     0.57220E-03     0.84730E-02


DIFFUSION COEFFICIENTS

  0.17070E 01     0.85360E 00     0.39510E 00

  0.17070E 01     0.85360E 00     0.39510E 00

  0.17070E 01     0.85360E 00     0.39510E 00

  0.19300E 01     0.91730E 00     0.31470E 00


TRANSFER CROSS-SECTIONS

  0.61130E-01     0.49440E-01     0.0

  0.61130E-01     0.49440E-01     0.0

  0.61130E-01     0.49440E-01     0.0

  0.26280E-01     0.28110E-01     0.0


NU-FISSION

  0.42920E-02     0.15060E-01     0.16400E 00

  0.42920E-02     0.15060E-01     0.16400E 00

  0.42920E-02     0.15060E-01     0.16400E 00


KAPPA-FISSION

  0.93280E-13     0.19010E-12     0.21290E-11

  0.93280E-13     0.19010E-12     0.21290E-11

  0.93280E-13     0.19010E-12     0.21290E-11

POWER (W) =  0.24410E 10
```

RESULTS

RADII OF REGIONS

REGION 1	REGION 2	REGION 3	REGION 4	REGION 5
0.0	87.70	124.00	152.00	159.00

EIGENVALUE OF THE UNPOISONED REACTOR K = 0.97971E 00

CONTROL POISON WAS USED IN THE FOLLOWING REGIONS

ALL FISSION REGIONS

MACRO CROSS-SECTION OF THE POISON= -0.37987E-02

POISON CONCENTRATION = -0.18012E 19

FLUXES NORMALIZED TO SOURCE

FAST FLUX-GROUP 1

0.42922E-03	0.42904E-03	0.42848E-03	0.42755E-03	0.42625E-03
0.42457E-03	0.42253E-03	0.42012E-03	0.41734E-03	0.41420E-03
0.41070E-03	0.40683E-03	0.40261E-03	0.39804E-03	0.39312E-03
0.38785E-03	0.38224E-03	0.37629E-03	0.37002E-03	0.36342E-03
0.35650E-03	0.34927E-03	0.34173E-03	0.33390E-03	0.32578E-03
0.31737E-03	0.30870E-03	0.29977E-03	0.29059E-03	0.28117E-03
0.27153E-03	0.26543E-03	0.25925E-03	0.25300E-03	0.24667E-03
0.24027E-03	0.23381E-03	0.22728E-03	0.22069E-03	0.21404E-03
0.20734E-03	0.20059E-03	0.19379E-03	0.18696E-03	0.18008E-03
0.17317E-03	0.16623E-03	0.15926E-03	0.15228E-03	0.14527E-03
0.13825E-03	0.13282E-03	0.12740E-03	0.12197E-03	0.11654E-03
0.11111E-03	0.10569E-03	0.10027E-03	0.94856E-04	0.89454E-04
0.84063E-04	0.78686E-04	0.73325E-04	0.67980E-04	0.62653E-04
0.57341E-04	0.52038E-04	0.46722E-04	0.41343E-04	0.35784E-04
0.29774E-04	0.23213E-04	0.17707E-04	0.13012E-04	0.89179E-05

RESONANCE FLUX-GROUP 2

0.34819E-03	0.34804E-03	0.34759E-03	0.34683E-03	0.34577E-03
0.34441E-03	0.34275E-03	0.34080E-03	0.33854E-03	0.33599E-03
0.33314E-03	0.33001E-03	0.32658E-03	0.32287E-03	0.31887E-03
0.31459E-03	0.31004E-03	0.30521E-03	0.30012E-03	0.29476E-03
0.28914E-03	0.28327E-03	0.27716E-03	0.27080E-03	0.26421E-03
0.25739E-03	0.25036E-03	0.24311E-03	0.23566E-03	0.22802E-03
0.22019E-03	0.21525E-03	0.21023E-03	0.20516E-03	0.20003E-03
0.19484E-03	0.18959E-03	0.18429E-03	0.17895E-03	0.17356E-03
0.16812E-03	0.16265E-03	0.15714E-03	0.15159E-03	0.14602E-03
0.14041E-03	0.13478E-03	0.12913E-03	0.12347E-03	0.11778E-03
0.11209E-03	0.10769E-03	0.10329E-03	0.98890E-04	0.94487E-04
0.90086E-04	0.85687E-04	0.81293E-04	0.76904E-04	0.72522E-04
0.68149E-04	0.63786E-04	0.59433E-04	0.55091E-04	0.50761E-04
0.46441E-04	0.42132E-04	0.37833E-04	0.33548E-04	0.29291E-04
0.25108E-04	0.20280E-04	0.15418E-04	0.10537E-04	0.55811E-05

SLOW FLUX-GROUP 3

0.12748E-03	0.12742E-03	0.12726E-03	0.12698E-03	0.12659E-03
0.12609E-03	0.12549E-03	0.12477E-03	0.12394E-03	0.12301E-03
0.12197E-03	0.12082E-03	0.11956E-03	0.11820E-03	0.11674E-03
0.11517E-03	0.11351E-03	0.11174E-03	0.10987E-03	0.10791E-03
0.10586E-03	0.10371E-03	0.10147E-03	0.99139E-04	0.96725E-04
0.94229E-04	0.91653E-04	0.89000E-04	0.86272E-04	0.83474E-04
0.80609E-04	0.78797E-04	0.76962E-04	0.75105E-04	0.73225E-04
0.71325E-04	0.69405E-04	0.67466E-04	0.65509E-04	0.63535E-04
0.61545E-04	0.59541E-04	0.57524E-04	0.55494E-04	0.53452E-04
0.51401E-04	0.49340E-04	0.47272E-04	0.45197E-04	0.43117E-04
0.41033E-04	0.39423E-04	0.37812E-04	0.36200E-04	0.34588E-04
0.32977E-04	0.31367E-04	0.29758E-04	0.28152E-04	0.26548E-04
0.24948E-04	0.23353E-04	0.21764E-04	0.20186E-04	0.18625E-04
0.17100E-04	0.15647E-04	0.14350E-04	0.13391E-04	0.13176E-04
0.14593E-04	0.16797E-04	0.14841E-04	0.99331E-05	0.30294E-05

FLUXES NORMALIZED TO POWER

FAST FLUX-GROUP 1

0.21237E 15	0.21228E 15	0.21200E 15	0.21154E 15	0.21090E 15
0.21007E 15	0.20906E 15	0.20787E 15	0.20649E 15	0.20494E 15
0.20320E 15	0.20129E 15	0.19920E 15	0.19694E 15	0.19451E 15
0.19190E 15	0.18912E 15	0.18618E 15	0.18308E 15	0.17981E 15
0.17639E 15	0.17281E 15	0.16908E 15	0.16520E 15	0.16119E 15
0.15703E 15	0.15274E 15	0.14832E 15	0.14378E 15	0.13912E 15
0.13435E 15	0.13133E 15	0.12827E 15	0.12518E 15	0.12205E 15
0.11888E 15	0.11568E 15	0.11245E 15	0.10919E 15	0.10590E 15
0.10259E 15	0.99247E 14	0.95885E 14	0.92502E 14	0.89100E 14
0.85681E 14	0.82248E 14	0.78801E 14	0.75343E 14	0.71876E 14
0.68402E 14	0.65719E 14	0.63034E 14	0.60347E 14	0.57661E 14
0.54975E 14	0.52291E 14	0.49610E 14	0.46933E 14	0.44260E 14
0.41593E 14	0.38932E 14	0.36279E 14	0.33635E 14	0.30999E 14
0.28371E 14	0.25747E 14	0.23117E 14	0.20456E 14	0.17705E 14
0.14731E 14	0.11485E 14	0.87612E 13	0.64379E 13	0.44124E 13

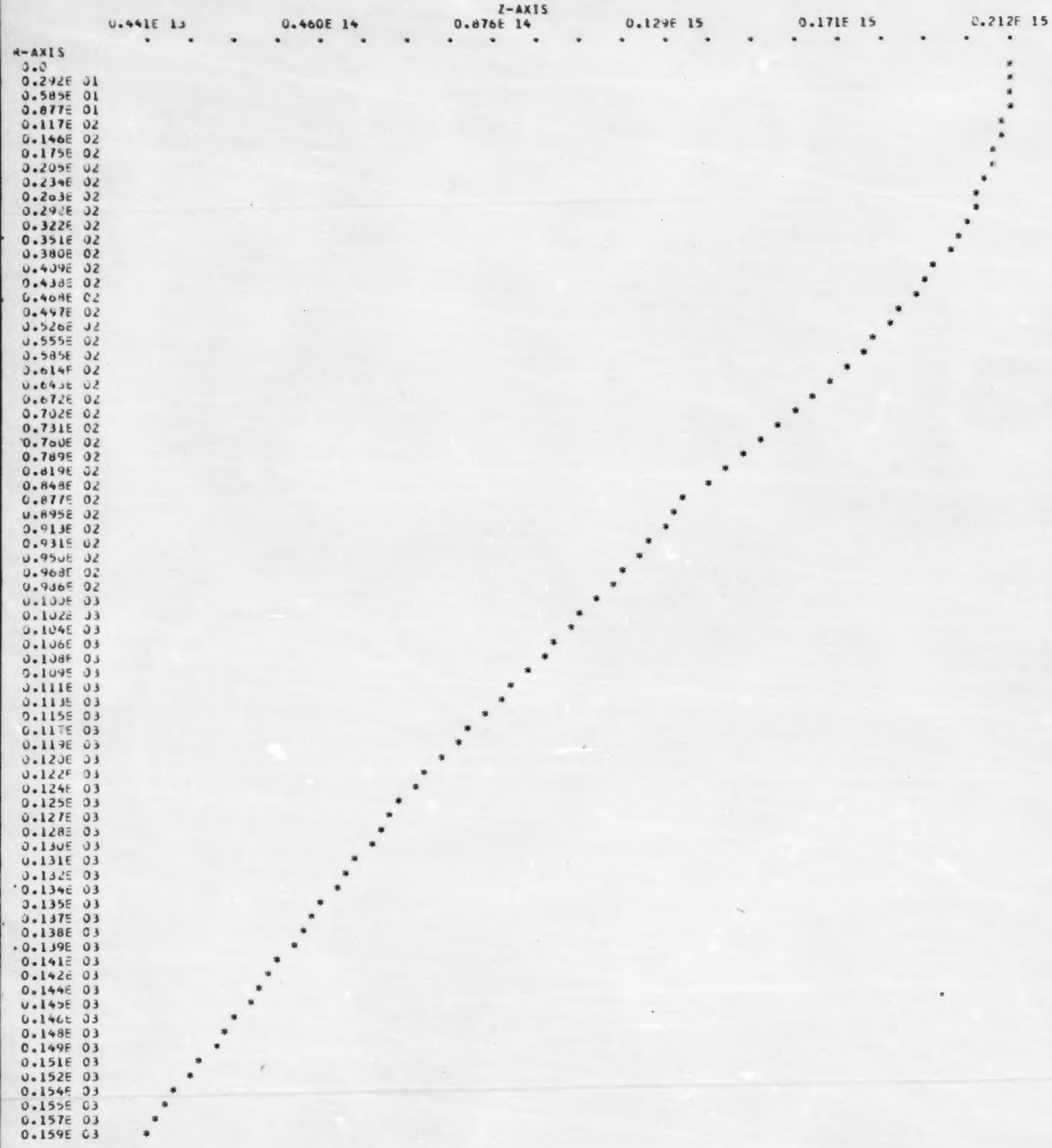
RESONANCE FLUX-GROUP 2

0.17228E 15	0.17220E 15	0.17198E 15	0.17160E 15	0.17108E 15
0.17041E 15	0.16959E 15	0.16862E 15	0.16750E 15	0.16624E 15
0.16483E 15	0.16328E 15	0.16159E 15	0.15975E 15	0.15777E 15
0.15565E 15	0.15340E 15	0.15101E 15	0.14849E 15	0.14584E 15
0.14306E 15	0.14016E 15	0.13713E 15	0.13399E 15	0.13073E 15
0.12735E 15	0.12387E 15	0.12029E 15	0.11660E 15	0.11282E 15
0.10895E 15	0.10650E 15	0.10402E 15	0.10151E 15	0.98969E 14
0.96400E 14	0.93805E 14	0.91185E 14	0.88540E 14	0.85872E 14
0.83184E 14	0.80475E 14	0.77748E 14	0.75005E 14	0.72246E 14
0.69473E 14	0.66688E 14	0.63893E 14	0.61089E 14	0.58277E 14
0.55460E 14	0.53284E 14	0.51107E 14	0.48929E 14	0.46750E 14
0.44572E 14	0.42396E 14	0.40222E 14	0.38050E 14	0.35882E 14
0.33719E 14	0.31560E 14	0.29406E 14	0.27258E 14	0.25115E 14
0.22978E 14	0.20846E 14	0.18719E 14	0.16599E 14	0.14493E 14
0.12423E 14	0.10034E 14	0.76287E 13	0.52137E 13	0.27614E 13

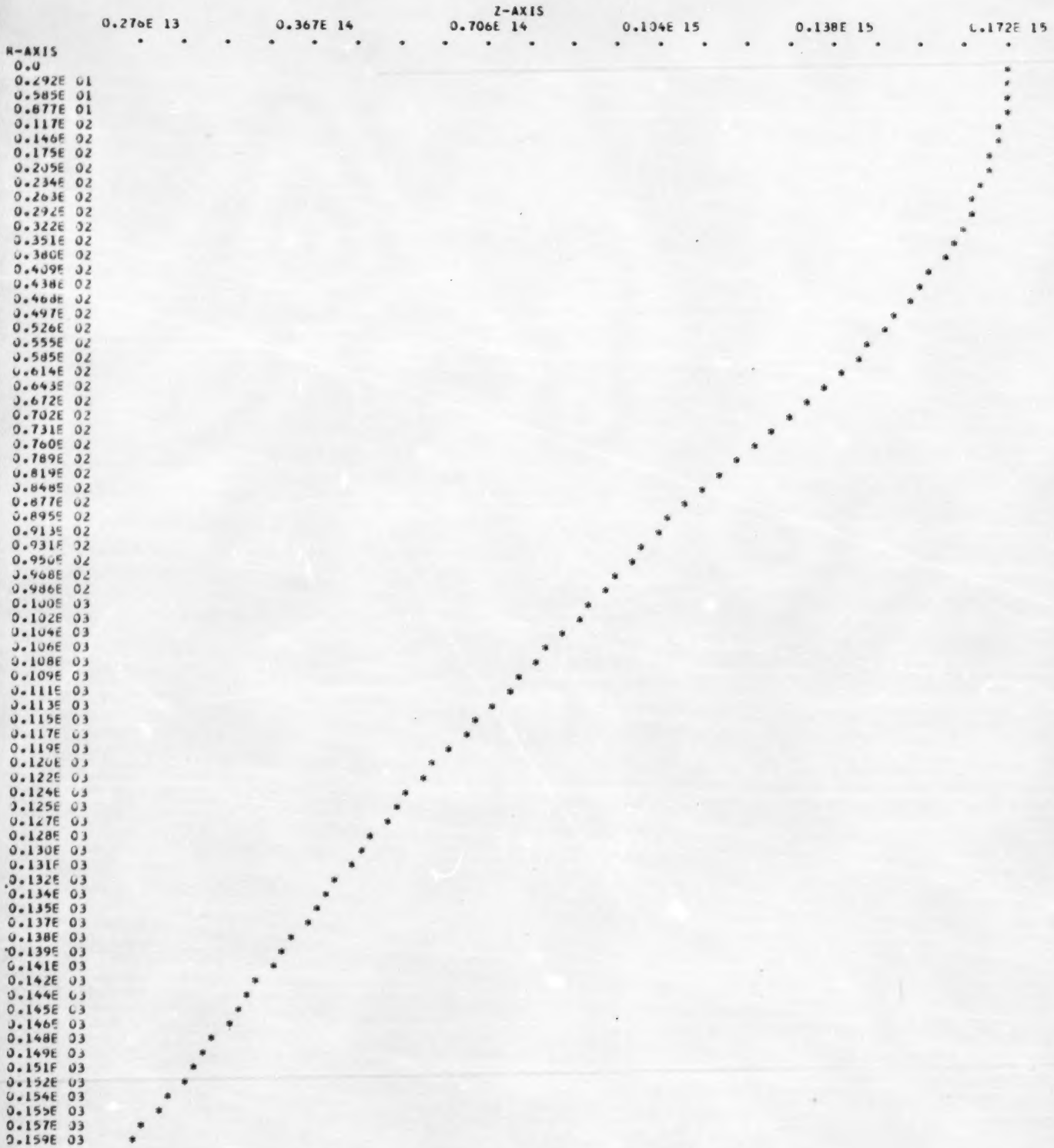
SLOW FLUX-GROUP 3

0.63073E 14	0.63046E 14	0.62963E 14	0.62826E 14	0.62635E 14
0.62388E 14	0.62088E 14	0.61733E 14	0.61324E 14	0.60862E 14
0.60347E 14	0.59778E 14	0.59158E 14	0.58485E 14	0.57761E 14
0.56986E 14	0.56161E 14	0.55286E 14	0.54363E 14	0.53392E 14
0.52375E 14	0.51311E 14	0.50203E 14	0.49052E 14	0.47858E 14
0.46623E 14	0.45348E 14	0.44035E 14	0.42686E 14	0.41301E 14
0.39883E 14	0.38987E 14	0.38079E 14	0.37160E 14	0.36230E 14
0.35290E 14	0.34340E 14	0.33380E 14	0.32412E 14	0.31436E 14
0.30451E 14	0.29460E 14	0.28461E 14	0.27457E 14	0.26447E 14
0.25432E 14	0.24412E 14	0.23389E 14	0.22363E 14	0.21333E 14
0.20302E 14	0.19506E 14	0.18708E 14	0.17911E 14	0.17114E 14
0.16316E 14	0.15520E 14	0.14724E 14	0.13929E 14	0.13135E 14
0.12344E 14	0.11554E 14	0.10768E 14	0.99874E 13	0.92153E 13
0.84606E 13	0.77418E 13	0.70999E 13	0.66258E 13	0.65193E 13
0.72204E 13	0.83110E 13	0.73431E 13	0.49147E 13	0.14989E 13

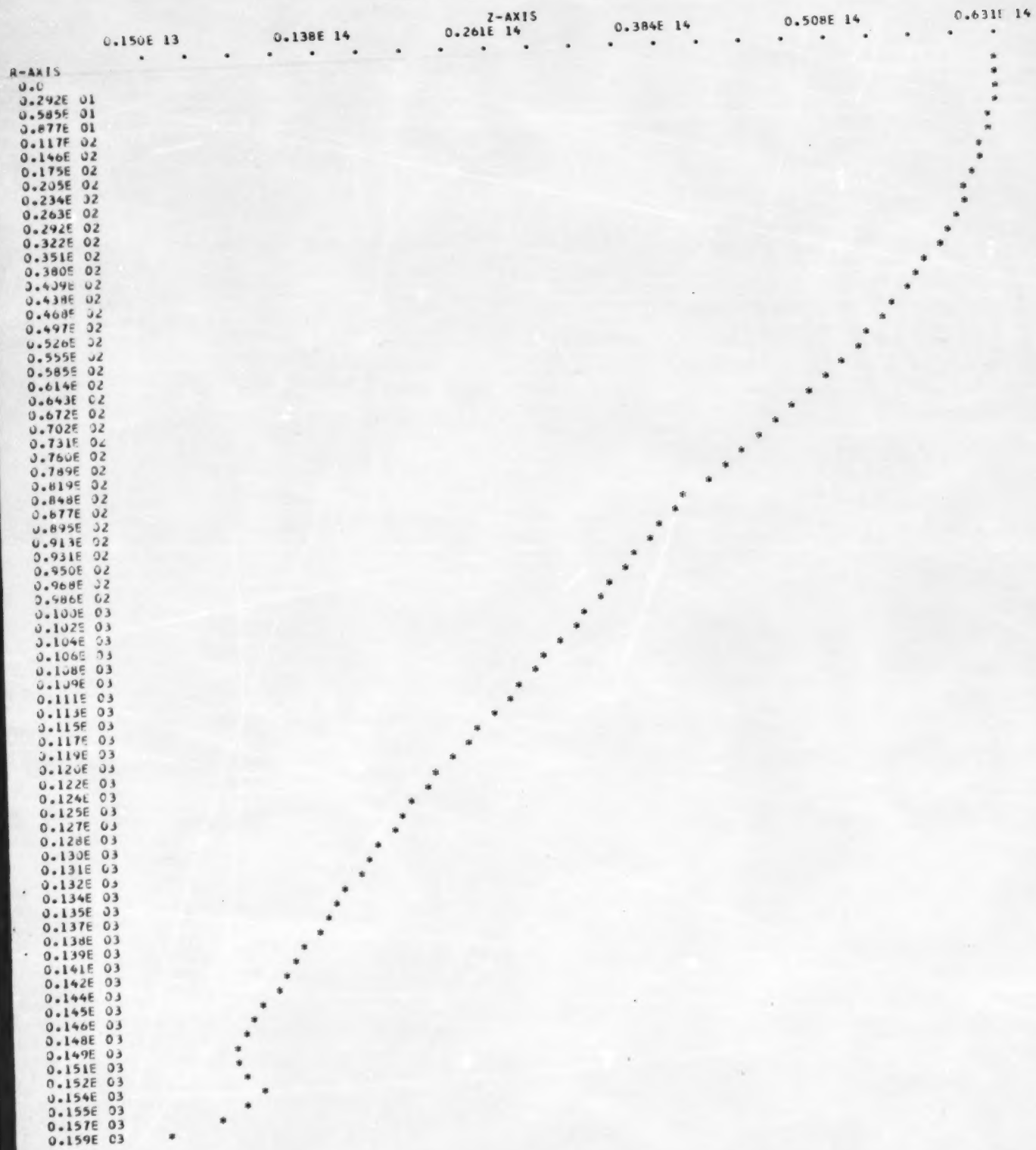
PLOT OF FAST FLUX - GROUP 1



PLOT OF RESONANCE FLUX -GROUP 2



PLOT OF SLOW FLUX - GROUP 3



RELATIVE FLUXES

GROUP 1

0.10000E 01	0.99957E 00	0.99826E 00	0.99609E 00	0.99306E 00
0.98916E 00	0.98440E 00	0.97879E 00	0.97232E 00	0.96500E 00
0.95683E 00	0.94783E 00	0.93800E 00	0.92735E 00	0.91588E 00
0.90360E 00	0.89053E 00	0.87668E 00	0.86206E 00	0.84668E 00
0.83056E 00	0.81371E 00	0.79616E 00	0.77791E 00	0.75899E 00
0.73942E 00	0.71921E 00	0.69841E 00	0.67702E 00	0.65507E 00
0.63260E 00	0.61839E 00	0.60400E 00	0.58943E 00	0.57469E 00
0.55978E 00	0.54472E 00	0.52950E 00	0.51415E 00	0.49866E 00
0.48305E 00	0.46733E 00	0.45153E 00	0.43557E 00	0.41955E 00
0.40345E 00	0.38728E 00	0.37105E 00	0.35477E 00	0.33845E 00
0.32209E 00	0.30945E 00	0.29681E 00	0.28416E 00	0.27151E 00
0.25886E 00	0.24623E 00	0.23360E 00	0.22099E 00	0.20841E 00
0.19585E 00	0.18332E 00	0.17083E 00	0.15838E 00	0.14597E 00
0.13359E 00	0.12124E 00	0.10885E 00	0.96321E-01	0.83369E-01
0.69366E-01	0.54081E-01	0.41254E-01	0.30314E-01	0.20777E-01

GROUP 2

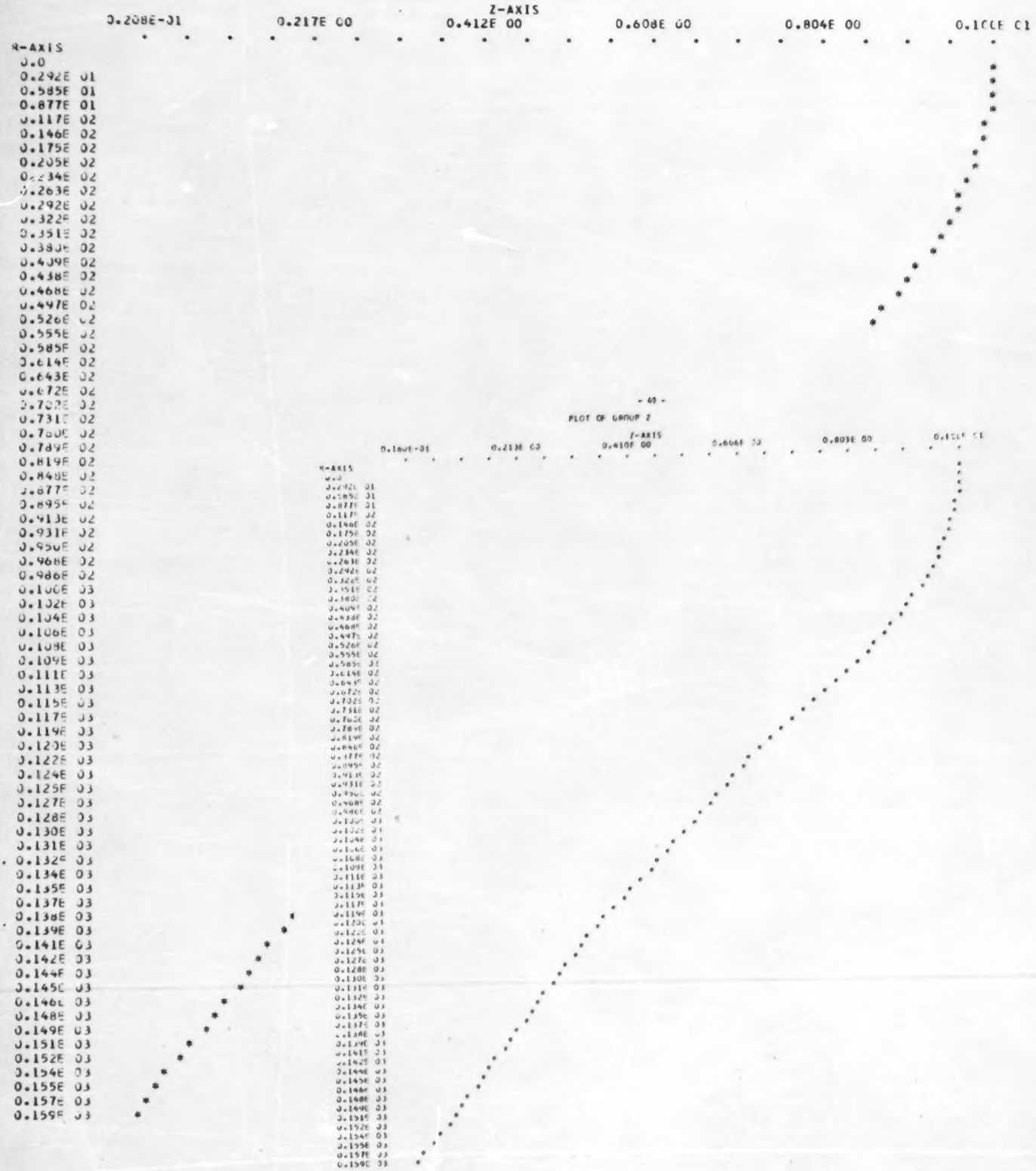
0.10000E 01	0.99957E 00	0.99826E 00	0.99609E 00	0.99305E 00
0.98915E 00	0.98439E 00	0.97876E 00	0.97229E 00	0.96496E 00
0.95679E 00	0.94778E 00	0.93794E 00	0.92727E 00	0.91580E 00
0.90351E 00	0.89043E 00	0.87657E 00	0.86194E 00	0.84655E 00
0.83042E 00	0.81356E 00	0.79600E 00	0.77774E 00	0.75881E 00
0.73923E 00	0.71902E 00	0.69821E 00	0.67682E 00	0.65487E 00
0.63239E 00	0.61818E 00	0.60379E 00	0.58922E 00	0.57447E 00
0.55957E 00	0.54450E 00	0.52929E 00	0.51394E 00	0.49846E 00
0.48285E 00	0.46713E 00	0.45130E 00	0.43537E 00	0.41936E 00
0.40326E 00	0.38710E 00	0.37087E 00	0.35460E 00	0.33828E 00
0.32192E 00	0.30930E 00	0.29666E 00	0.28401E 00	0.27137E 00
0.25873E 00	0.24609E 00	0.23347E 00	0.22087E 00	0.20828E 00
0.19572E 00	0.18319E 00	0.17069E 00	0.15822E 00	0.14578E 00
0.13338E 00	0.12100E 00	0.10866E 00	0.96349E-01	0.84124E-01
0.72109E-01	0.58245E-01	0.44281E-01	0.30263E-01	0.16029E-01

GROUP 3

0.10000E 01	0.99957E 00	0.99826E 00	0.99609E 00	0.99305E 00
0.98915E 00	0.98438E 00	0.97876E 00	0.97228E 00	0.96495E 00
0.95678E 00	0.94776E 00	0.93792E 00	0.92725E 00	0.91577E 00
0.90349E 00	0.89041E 00	0.87654E 00	0.86191E 00	0.84652E 00
0.83038E 00	0.81352E 00	0.79596E 00	0.77770E 00	0.75877E 00
0.73918E 00	0.71897E 00	0.69816E 00	0.67677E 00	0.65482E 00
0.63234E 00	0.61813E 00	0.60373E 00	0.58916E 00	0.57442E 00
0.55951E 00	0.54445E 00	0.52924E 00	0.51388E 00	0.49840E 00
0.48279E 00	0.46707E 00	0.45125E 00	0.43532E 00	0.41931E 00
0.40321E 00	0.38705E 00	0.37083E 00	0.35455E 00	0.33823E 00
0.32188E 00	0.30925E 00	0.29662E 00	0.28397E 00	0.27133E 00
0.25869E 00	0.24606E 00	0.23344E 00	0.22084E 00	0.20826E 00
0.19571E 00	0.18319E 00	0.17073E 00	0.15835E 00	0.14611E 00
0.13414E 00	0.12274E 00	0.11257E 00	0.10505E 00	0.10336E 00
0.11448E 00	0.13177E 00	0.11642E 00	0.77920E-01	0.23764E-01

- 48 -

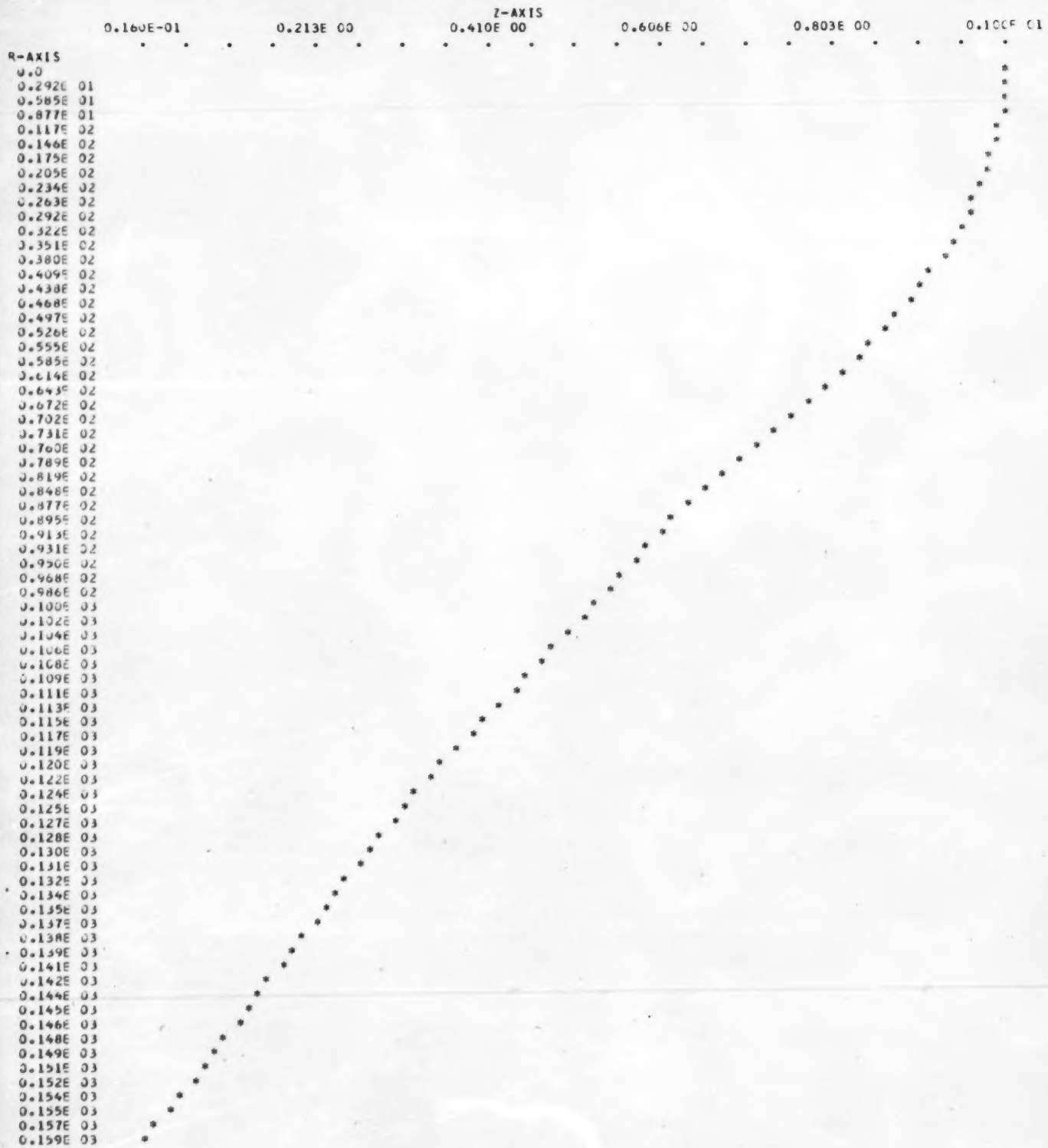
PLOT OF GROUP 1



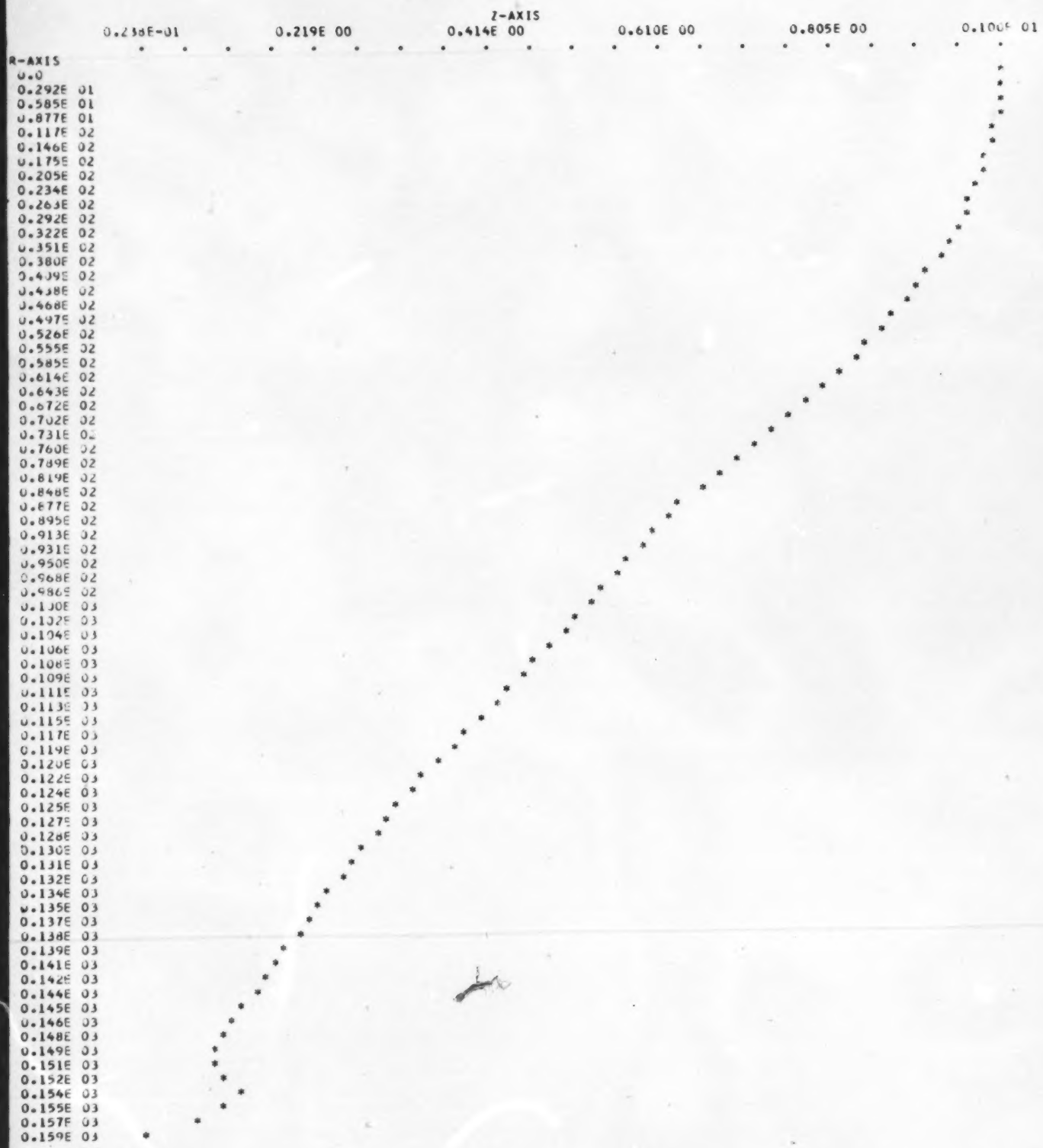
- 49 -

PLOT OF GROUP 2

PLOT OF GROUP 2



PLOT OF GROUP 3



RATIOS OF FLUXES TO THE SLOW FLUX

GROUP 1 / GROUP 3

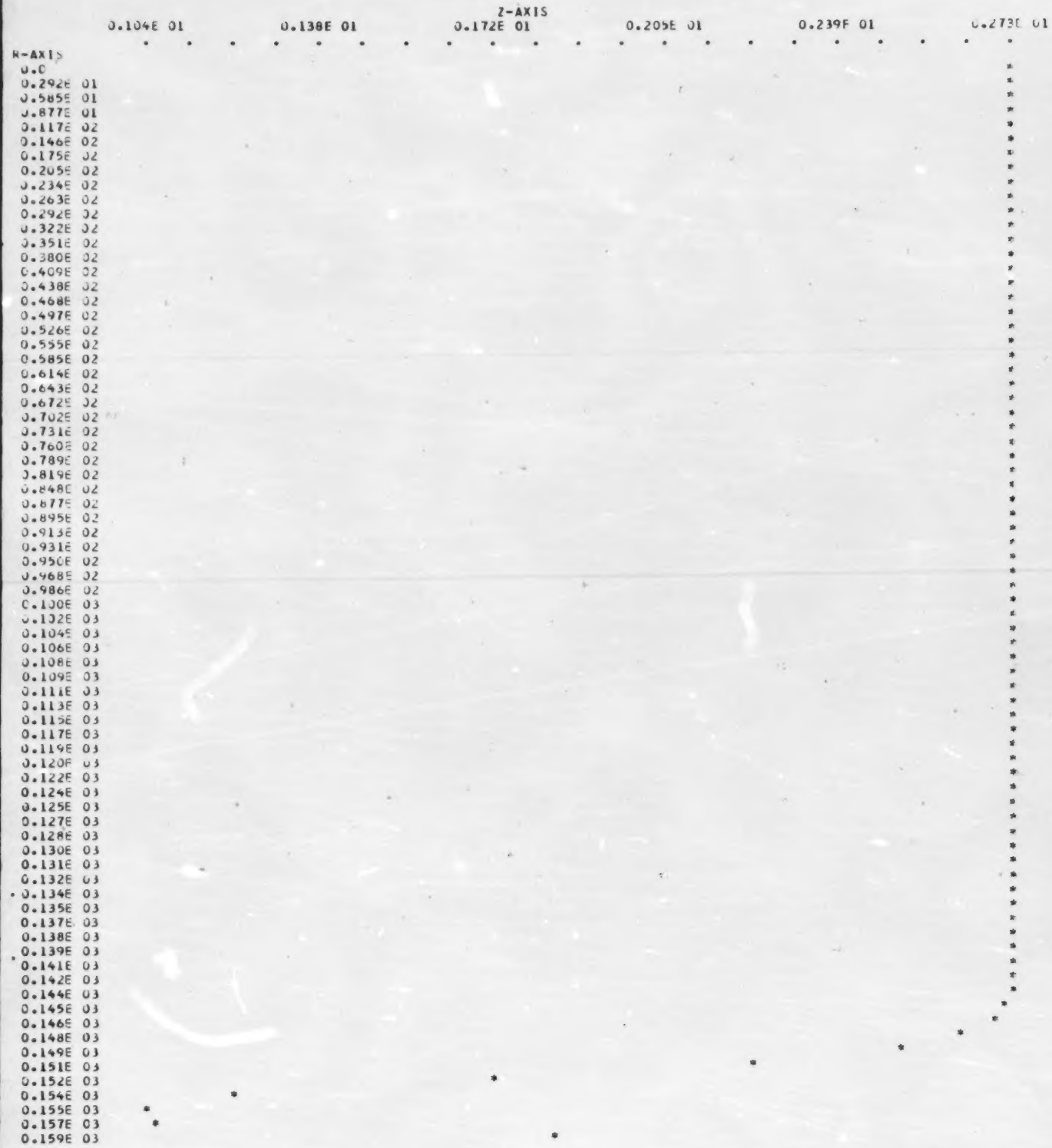
0.33671E 01	0.33671E 01	0.33671E 01	0.33671E 01	0.33671E 01
0.33671E 01	0.33671E 01	0.33672E 01	0.33672E 01	0.33672E 01
0.33673E 01	0.33673E 01	0.33673E 01	0.33674E 01	0.33674E 01
0.33675E 01	0.33675E 01	0.33676E 01	0.33677E 01	0.33677E 01
0.33678E 01	0.33679E 01	0.33679E 01	0.33680E 01	0.33680E 01
0.33681E 01	0.33682E 01	0.33683E 01	0.33683E 01	0.33684E 01
0.33685E 01	0.33685E 01	0.33686E 01	0.33686E 01	0.33686E 01
0.33687E 01	0.33687E 01	0.33688E 01	0.33688E 01	0.33688E 01
0.33689E 01	0.33689E 01	0.33689E 01	0.33690E 01	0.33690E 01
0.33690E 01	0.33691E 01	0.33691E 01	0.33691E 01	0.33692E 01
0.33692E 01	0.33692E 01	0.33693E 01	0.33693E 01	0.33693E 01
0.33693E 01	0.33694E 01	0.33694E 01	0.33694E 01	0.33695E 01
0.33695E 01	0.33695E 01	0.33691E 01	0.33677E 01	0.33639E 01
0.33533E 01	0.33257E 01	0.32559E 01	0.30873E 01	0.27158E 01
0.20403E 01	0.13819E 01	0.11931E 01	0.13099E 01	0.29438E 01

GROUP 2 / GROUP 3

0.27314E 01	0.27314E 01	0.27314E 01	0.27314E 01	0.27314E 01
0.27314E 01	0.27314E 01	0.27314E 01	0.27314E 01	0.27314E 01
0.27314E 01	0.27314E 01	0.27314E 01	0.27314E 01	0.27315E 01
0.27315E 01	0.27315E 01	0.27315E 01	0.27315E 01	0.27315E 01
0.27315E 01	0.27315E 01	0.27315E 01	0.27315E 01	0.27316E 01
0.27316E 01	0.27316E 01	0.27316E 01	0.27316E 01	0.27316E 01
0.27316E 01	0.27316E 01	0.27316E 01	0.27316E 01	0.27317E 01
0.27317E 01	0.27317E 01	0.27317E 01	0.27317E 01	0.27317E 01
0.27317E 01	0.27317E 01	0.27317E 01	0.27317E 01	0.27317E 01
0.27317E 01	0.27317E 01	0.27317E 01	0.27317E 01	0.27317E 01
0.27317E 01	0.27318E 01	0.27318E 01	0.27318E 01	0.27318E 01
0.27318E 01	0.27318E 01	0.27318E 01	0.27318E 01	0.27317E 01
0.27316E 01	0.27314E 01	0.27308E 01	0.27292E 01	0.27254E 01
0.27159E 01	0.26927E 01	0.26365E 01	0.25052E 01	0.22230E 01
0.17205E 01	0.12074E 01	0.10389E 01	0.10608E 01	0.18423E 01

PLOT OF GROUP 1 / GROUP 3

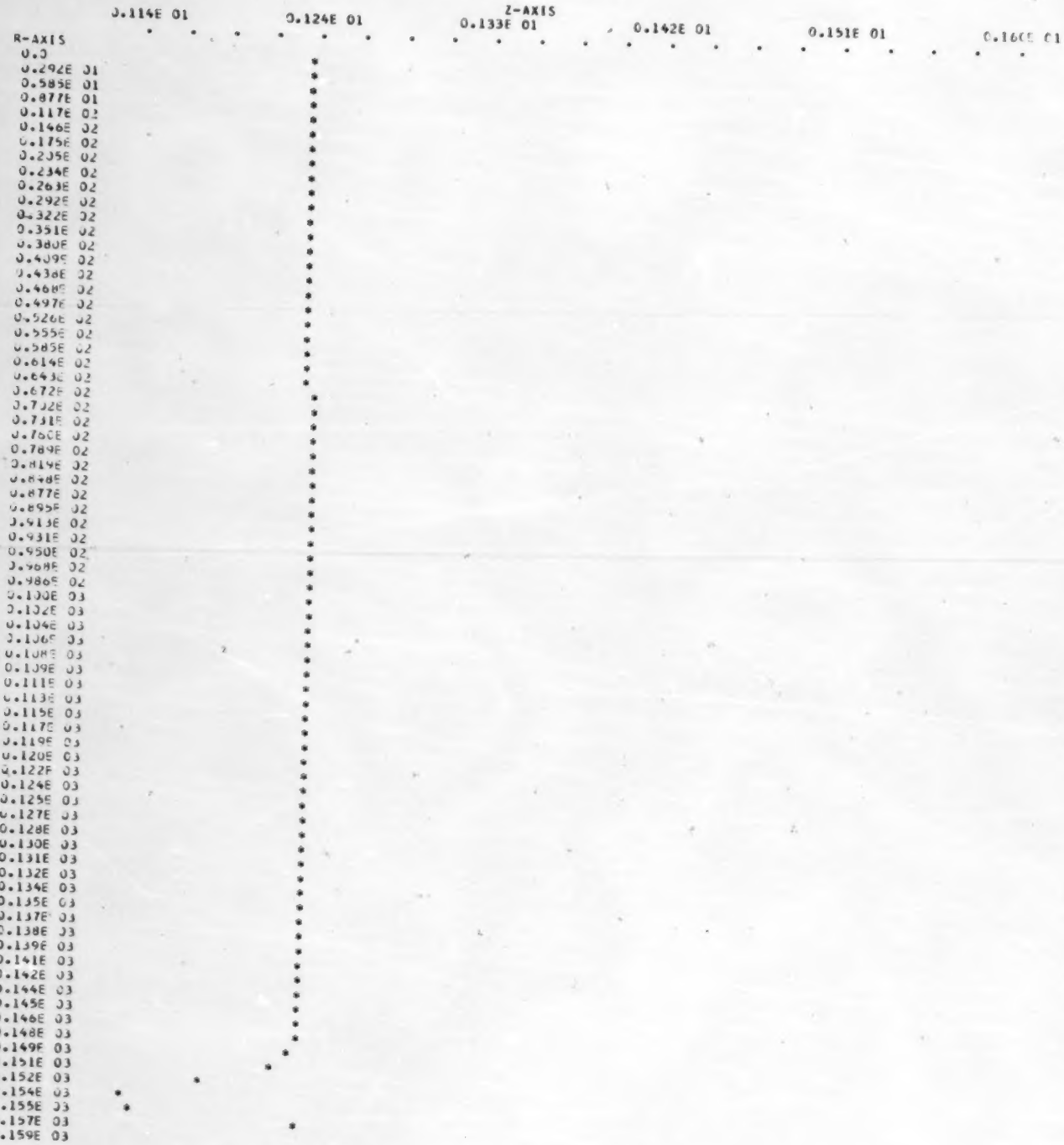
PLOT OF GROUP 2 / GROUP 3



GROUP 1 / GROUP 2

0.12327E 01	0.12327E 01	0.12327E 01	0.12327E 01	0.12327E 01
0.12327E 01	0.12327E 01	0.12328E 01	0.12328E 01	0.12328E 01
0.12328E 01	0.12328E 01	0.12328E 01	0.12328E 01	0.12328E 01
0.12329E 01	0.12329E 01	0.12329E 01	0.12329E 01	0.12329E 01
0.12329E 01	0.12330E 01	0.12330E 01	0.12330E 01	0.12330E 01
0.12330E 01	0.12331E 01	0.12331E 01	0.12331E 01	0.12331E 01
0.12331E 01	0.12331E 01	0.12332E 01	0.12332E 01	0.12332E 01
0.12332E 01	0.12332E 01	0.12332E 01	0.12332E 01	0.12332E 01
0.12333E 01	0.12333E 01	0.12333E 01	0.12333E 01	0.12333E 01
0.12333E 01	0.12333E 01	0.12333E 01	0.12333E 01	0.12333E 01
0.12333E 01	0.12334E 01	0.12334E 01	0.12334E 01	0.12334E 01
0.12334E 01	0.12334E 01	0.12334E 01	0.12334E 01	0.12335E 01
0.12335E 01	0.12336E 01	0.12337E 01	0.12339E 01	0.12343E 01
0.12347E 01	0.12351E 01	0.12349E 01	0.12324E 01	0.12217E 01
0.11858E 01	0.11446E 01	0.11485E 01	0.12348E 01	0.15979E 01

PLOT OF GROUP 1 / GROUP 2



POWER OUTPUT IN REGIONS 1,2,3

0.13406E 10 0.77863E 09 0.32180E 09

POWER DENSITY IN REGIONS 1,2,3 (KW/LITER)

0.15171E 03 0.13348E 01 0.54903E 00

COMPUTED OVERRELAXATION FACTOR= 1.900